Metal Progress

Metal Progress

May 1961 . . . Vol. 79, No. 5

COVER: This month's cover, designed by ROLAND MAHONEY, is one of the prizewinner's in the annual *Metal Progress* cover competition held at the Cleveland Institute of Art.

Technical News in Brief

New Nickel Steels Exhibit Strength and Toughness . . . Outlook for Oxygen in Steelmaking . . . Rare-Earth Sulfides Used as Thermoelectric Materials . . . Tungsten Shapes Made by Centrifugal Casting . . . Steel Gears Produced on Automatic Equipment . . . Controlled Impurities in Uranium . . . Hot Rolling Welds Sandwich Panels . . . Progress on Nonmetallic Materials . . . Tool Steels in Today's Industry 7

In Memoriam

Ernest E. Thum 64-A

Advances in Vacuum Technology

Consumable-Electrode Melting of Steels . . . Present and Future, by W. W. Dyrkacz 65

Since its adaptation to specialty steel and superalloys, consumable-electrode vacuum melting has proved to be a valuable technique for obtaining cleaner ingots which have lower gas content and better mechanical properties than comparable air-melted ingots. As a consequence, larger and larger remelting units are being built, and 60,000-lb. ingots will soon be available. (D5, D8m, D9)*

Pouring Degassed Steel in an Argon Atmosphere, by William Wilson 71

Ingot molds can now be filled with argon, an inert gas 38% heavier than air, to prevent ladle degassed steel from picking up hydrogen, oxygen and nitrogen when it is teemed. The result: Improved macroetches, fewer inclusions, higher ductilities, and good ingot surfaces. (D9s)

Deoxidizing Steels by Vacuum, by G. E. Danner and E. Dyble 74

When unkilled steel is stream degassed in a vacuum, included oxygen will unite with the carbon in the steel, and boil off as carbon monoxide. Extensive tests show that steel deoxidized in this manner will contain less gases and fewer inclusions. (D9s, 1-73, D8m)

Engineering Articles

AM 355 for Gas Turbine Engines, by Paul A. Bergman 79

AM 355, a controlled-transformation stainless steel, offers an excellent combination of the better features found in the 300 and 400 series. This article discusses general characteristics and properties of AM 355 forgings and bar stock, including the effects of retained austenite and its control. (A-general, T24b, Q-general; SS)

Sintered Iron Piston Rings, by Robert Talmage 89

Sintered iron rings are stronger and more wear resistant than cast iron rings and in addition are self-lubricating. They have a cleaner, more uniform microstructure and can be produced at lower cost. (T7, 17-57; Fe, 6-72)

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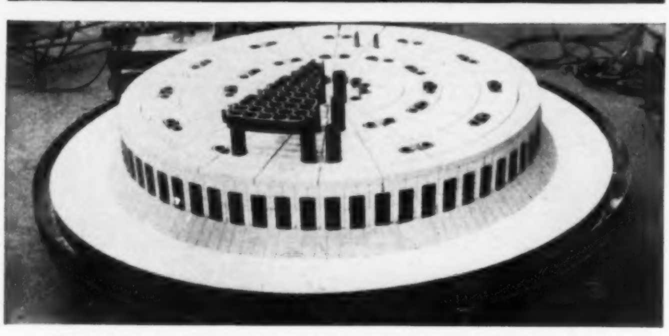
**The coding symbols refer to the ASM-SLA Metallurgical Literature Classification, International (Second) Edition, 1958*

New Alloy Supertherm* proves itself in 2300 degree fahrenheit brazing furnace



Supertherm hearth grid segment during furnace construction.

In a brazing furnace for the thrust chambers of rocket engines at Rocketdyne Division of North American Aviation, Inc., Canoga Park, Cal., a Supertherm furnace hearth grid assembly is operating at a temperature of 2300° F. The grid in a furnace built by the General Electric Company's Industrial Heating Department at Shelbyville, Ind., supports the engine parts during a brazing cycle of from five to eight hours with a maximum temperature of 2300° F. At this extreme temperature and under severe conditions of thermal fatigue created by the brazing cycle, *the Supertherm grid has performed successfully over one year.*

Supertherm is Electro-Alloys' new alloy for the 1800 to 2300 degree fahrenheit range. The composition of Supertherm is 26% chromium, 35% nickel, and is strengthened and stabilized with cobalt and tungsten. For technical information about the composition, physical and high temperature properties of Supertherm, fill out and return the coupon or contact your local Electro-Alloys representative.

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Metal Progress

Drilling Holes to Measure Residual Stresses, by Arthur J. Bush **91**

In this method, a small hole is drilled into the test specimen to relieve the residual stresses. Drilling is stopped at specific intervals, and the changes in stress are determined by strain gages which surround the hole. (Q25h, G25, ST)

Phase Identification in Nickel-Base Alloys, by J. E. Wilson and J. F. Radavich **94**

As-cast structures contain gamma prime, Ni_3Al, a complex boride, and titanium carbonitride. During heat treatment the carbonitride breaks down and another complex carbide forms at its expense. Grain size and distribution of phases determine rupture life. (M27, M21e, M22g; Ni-b, SGA-h)

The Electron Microscope . . . a New Tool for Examining Fractures, by Austin Phillips and Guy V. Bennett **97**

Fracture surfaces of metals can now be examined at magnifications up to 50,000 × by the electron microscope. This technique, termed "electron microfractography", may become an important tool in failure analysis; it promises to reveal many of the heretofore undisclosed details associated with the various failure phenomena. (M12e, M23p)

Fabrication Studies on Columbium Alloy Sheet, by Andrew F. Trabold and Steven Bank **103**

Preliminary tests indicate that D-31 sheet (10% Mo, 10% Ti) has relatively good formability; its machining chacteristics are similar to austenitic stainless steel. The alloy has fair bendability, but its weldability leaves much to be desired. The material can be sheared cold; it can be dimpled at 500° F. but not at room temperature. (G-general, G17k, K9s, Q23q; Cb-b, 4-53)

Heat Processing of Stainless Steels

Furnace Brazing of Stainless Steel Assemblies, by H. M. Webber **108**

Furnace brazing – employing a variety of protective atmospheres, furnaces and filler metals – offers a number of advantages. Many flux-free, nonporous joints can be brazed simultaneously and economically, dissimilar metals with wide thickness variations can be joined, and close tolerances can be held. (K8j; SS)

Biographical Appreciation

A.S.M.'s President for 1960-61 – William Alvin Pennington, by Samuel J. Rosenberg **86**

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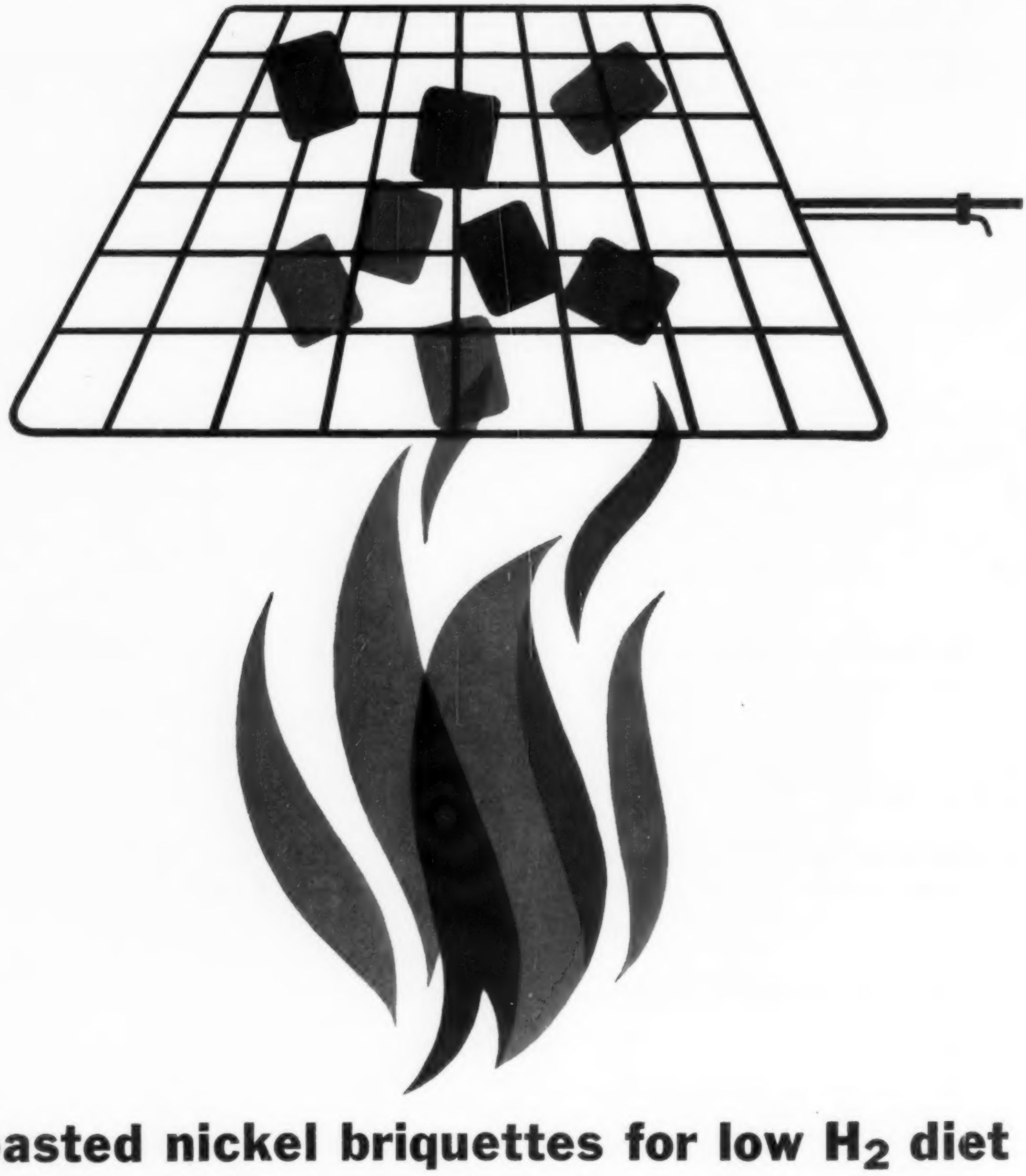

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Circle 1902 on Page 48-B

PRESS BREAKS

Several results of our continuing program to improve service to our readers are to be seen in this issue of *Metal Progress*. Technical News in Brief has been moved forward to a more prominent position in the magazine, following the table of contents and this column. At the same time, Art Director Floyd Craig has designed a new format for this section and for New Products and New Literature. Note that the symbols representing major technological areas, which were successfully introduced at the 1960 Metal Show (and were designed by Floyd), are put to effective use now in the New Literature and New Products column.

The design of these new formats is part of Floyd Craig's continuing effort to see that *Metal Progress* is typographically and artistically in the forefront of its field. Each month he works closely with the editors to arrange the articles in *Metal Progress* so that the most technical information can be attractively presented in the least number of pages. This entails sizing photographs to emphasize the most important points, redrawing graphs to our style for reproduction in color, drawing the many pieces of art which illustrate the special features, specifying typefaces – all directed toward giving the pages of *Metal Progress* a pleasing, well-balanced look.

You probably noticed the special News Report From the West presented in the April issue. A special effort was made to provide a timely report of the highlights of the Western Metal Congress which ended on March 24, only a week before the issue's mailing date. Editors Allen Gray and Ralph Dermott summarized the activities at the Congress and then, to meet the tight schedule, teletyped their final report to our printer in Mt. Morris, Ill. Ralph boarded a Chicago-bound jet and, after a night in the Windy City, continued his trip to Mt. Morris by train. There he checked over the awaiting page proofs of the special report, made some last-minute additions and OK'd it for the press. The April issue was then ready to roll and a complete run (totaling more than 39,000) was printed, bound, wrapped, addressed and mailed to our readers before March 31!

"Light Metallurgy" Goes to England

In May 1957, *Metal Progress*' "Light Metallurgy Dept." printed "A Glossary for Research Reports", by C. D. Graham, Jr. A recent mail has brought apologetic letters from the editors of two British journals claiming that they had both unintentionally "pirated" the article without giving credit to either *Metal Progress* or the original author. We were so mollified by the idea that material published in *Metal Progress* had such wide appeal that we informed them we would forgo any public apology!

The Editors

Circle 1904 on Page 48-B

New Nickel Steels Exhibit Strength and Toughness

In the November 1960 issue of *Metal Progress,* a new series of nickel steels containing 20 to 27% Ni (with about 1.5% Ti, 0.2% Al and 0.5% Cb) was announced. Since then, fabricators working with the steels in sheet form have reported that they possess a number of desirable properties. The steels can be cold rolled and deep drawn in the annealed condition, and, because of their low rate of work hardening, they will take cold reductions greater than 75% without intermediate anneals. Parts cold worked to this extent can then be age hardened to yield strengths greater than 250,000 psi. In addition, tests have revealed that the 20 to 27% Ni steels have excellent cryogenic properties and exhibit notched-to-unnotched tensile strength ratios greater than one. Several companies are producing the new steels in pilot quantities including Carpenter Steel Co., Kelsey-Hayes Co., Allegheny Ludlum Steel Corp. and Universal-Cyclops Steel Corp.

Since initial information was revealed on the 20 to 27% Ni steels, a modified variety containing 18% Ni, 7% Co, 5% Mo and less than 0.5% Ti has been developed by Inco metallurgists. This alloy can be heat treated to yield strengths greater than 250,000 psi. without raising the nil ductility temperature above −80° F. In addition, the high strength levels are accompanied by tensile elongations of at least 10% (round tensile bars).

Like the 20 to 27% Ni grades, the 18% Ni steel is strengthened by the combined effects of martensite formation and precipitation hardening. If proper finishing temperature (preferably about 1500° F.) is maintained off the mill, the steel can simply be air cooled to room temperature and aged at 900° F. for about 3 hr. Solution annealing at 1500° F. is considered an optional treatment, and quenching is not necessary. Significantly, the 18% Ni steel can be fully hardened in sections as thick as 6 in.

Welding characteristics are also good. No preheat is required even when fully heat treated steel is welded. Postweld aging will restore the original properties in the softened heat-affected zone.

Outlook for Oxygen in Steelmaking

Papers concerning the present and potential use of oxygen highlighted the 44th Conference of the National Open Hearth Steel Committee held April 10 and 11 in Philadelphia. Sponsored by the A.I.M.E., the meetings provided a clue to the direction that future use of oxygen will probably follow in the steel industry. In general, it appears that producers with large open-hearth capacity will attempt to adapt these familiar furnaces to oxygen operation. However, those companies that are

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Technical

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In Brief

erecting new installations are apparently swinging to basic oxygen converters of the L-D type — though a Kaldo rotary unit is to be installed at Sharon Steel Corp.

In open-hearth furnaces, the use of roof lances which inject oxygen alone or oxygen plus natural gas has provided greatly increased production rates. For example, Ford steelmen have, with the aid of oxygen-fuel lances, made 60 heats in a 200-ton furnace at rates averaging about 67 tons per hr. Their 400-ton furnace has done even better. With it, they have made 20 heats at an average rate of 96 tons per hr., their greatest production being 105 tons per hr. Engineers at Great Lakes Steel Corp., have also produced steel at similar rates. Their largest open hearth, which has a capacity of 500 tons and is equipped with oxygen-fuel lances, has produced steel at the rate of 152 tons per hr. from charge to tap.

In general, all companies that have installed roof lances feel that the full advantage of oxygen will be realized when certain auxiliary improvements are available, such as facilities for faster charging, especially for cold metal, would be helpful.

As for converters, Colorado Fuel and Iron, Jones & Laughlin, and Great Lakes Steel are adding new units of the L-D type. For example, Jones & Laughlin is now erecting two converters (at Cleveland), each of which is to have a rated capacity of 200 tons. With these, it expects to produce steel at the rate of 200 tons per hr. When in full production — operation is scheduled to begin in July 1961 — the converters may supplant eight open-hearth furnaces now in use.

Great Lakes Steel, in taking an even bigger step, is building a converter rated at 300 tons. To give an idea of its size, the two bull gears which tilt the vessel are nearly 16 ft. in diameter. Since enormous amounts of oxygen will be needed, Great Lakes is adding a 350-ton-per-day oxygen plant to the 100 and 500-ton units it already employs.

In short, it appears that the nation's steelmakers will continue to use more and more oxygen. The limit does not seem to be in sight.

Rare-Earth Sulfides Used as Thermoelectric Materials

Direct conversion of heat into electricity, previously discussed in *Metal Progress* (see September 1960, p. 65 and 108) has progressed another step with the introduction of varieties of two new thermoelectric compounds, samarium sulfide and cerium sulfide. The materials which are being made at Westinghouse Electric Corp., Pittsburgh, are expected to be used in future thermoelectric power generators. In these generators more efficient conversion of heat to electrical energy is obtained by employing several different types of thermoelectric materials in series or cascade to take advantage of the temperature range where each functions best. The cerium and samarium sulfides will be used as the hottest materials in such a series at temperatures up to 2000° F.

PREPARING THERMOELECTRIC COMPOUNDS
Sulfides of Samarium and Cerium Are Used Up to 2000° F. in Thermoelectric Generator

Both sulfides are prepared by direct combination of pure metal with sulfur which occurs when the two elements are heated to high temperatures in a protective atmosphere. After the reaction takes place, the resulting sulfide is crushed, compacted into cylindrical pellets and sintered in a vacuum induction furnace.

Tungsten Shapes Made by Centrifugal Casting

The melting point of tungsten (6170° F.), higher than any known element, certainly qualifies it as a refractory metal but also accounts for some difficult problems in processing. Until recently, for example, it has not been possible to cast tungsten shapes; parts made of the high-temperature metal have been, for the most part, hogged out of ingots

and it is not uncommon to machine parts weighing only 90 lb. from a 1000-lb. ingot.

Because of the economic advantages that tungsten castings would offer, metallurgists at Oregon Metallurgical Corp., Albany, Ore., have been engaged in an intensive program to work out practical foundry techniques. Recently they were successful in casting pure tungsten in the form of rings up to 10 in. in diameter and weighing 220 lb. Stephen M. Shelton, president of Oremet, said that melting is done in a vacuum arc furnace. The furnace, which draws 40,000 amp. at 40 v., melts the complete charge in a water-cooled copper crucible in 5 min. The hot metal is then cast centrifugally into graphite molds. Pouring temperature has not been determined.

Steel Gears Produced on Automatic Equipment

A good way to hold down production costs is to install high-speed automatic equipment. At the Marion (Ohio) Div., of Eaton Mfg. Co., a 6000-ton mechanical press, working with a 25-ft. diameter rotary hearth furnace and automatic conveyers is now turning out ring gears of 4718 H or 8720 H steel in three steps. This equipment replaces smaller hammers which needed 25 to 40 blows to forge the same gear.

Quality of the gears produced in this $1,000,000 installation is improved because every step is controlled automatically. An added benefit is that the amount of scrap is appreciably reduced.

The rotary hearth furnace employs 41 radiant burners and is capable of heating steel billets (7-in. cubes weighing 100 lb.) to 2400° F. at the rate of 150 pieces per hr. The 6000-ton Ajax press, driven by a 400 hp. motor, features an automatic manipulator which loads the heated billet onto the first-stage "buster" die, and then transfers the semifinished part to blocker and finish dies. Hot ring gear forgings are then trimmed, annealed (for improved machinability), cleaned and shipped to the customer for finish machining and carburizing. Additional details on this installation will appear in subsequent issues of *Metal Progress.*

Controlled Impurities in Uranium

Refining a metal is a practice which predates history – even if the metallurgist immediately puts back in some other impurities (alloying elements) to improve the mechanical properties. A new story is where a metal that contains a conglomeration of 40 to 45 other elements is treated so that a half-dozen of them are left behind!

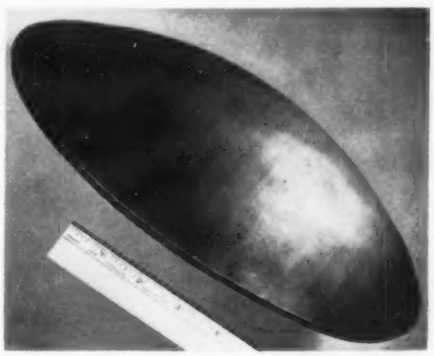
Such an instance was cited by Frank G. Foote, director of metallurgy at Argonne National Laboratory at the recent symposium on Materials for Nuclear Applications held at Albuquerque, N.M. Uranium, partly depleted in its fissionable isotope, U^{235}, is refined by a process that leaves behind a mixture of about 0.10% Zr, 0.28% Rh, 0.19% Pd, 0.10% Cb, 1.96% Ru and 2.46% Mo. This combination, dubbed "fissium" by the metallurgists, is not only harmless to the re-use of the reclaimed uranium in a new fuel element, but improves its physical properties – particularly its dimensional stability at reactor operating temperatures.

Hot Rolling Welds Sandwich Panels

Metallurgists at Battelle Memorial Institute in Columbus, Ohio, have devised a method for producing corrugated-core sandwich panels at reduced cost. The method – called roll welding – is the result of work sponsored by Douglas Aircraft Co. It requires no jigging, gives sound core-to-cover bonds, and permits panels to be formed extensively after assembly.

To date, panels of 2014 aluminum, B 120 VCA titanium, steel, molybdenum and Inconel 36 by 72 in. have been produced in thicknesses of ¼ in., but size is limited only by rolling-mill capacity.

In fabricating a sandwich panel, an assembly is first prepared by inserting solid filler wedges of copper or iron in the corrugations of the core sheet. Next, the core, with each corrugation supported by the metal wedges, is placed in a frame, the face sheets of the sandwich are positioned and



SANDWICH PANEL MADE BY HOT ROLLING
Metal Inserts Support Corrugations During Rolling and Forming Operations

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Technical NEWS In Brief

their exterior surfaces painted. Then the entire assembly is clamped between two metal cover sheets which are welded to the frame. This package is hot rolled in a direction parallel to the corrugations. During rolling, the core welds to the face sheets and thickness of the panel is reduced by as much as 60%. Paint on the face sheets prevents them from bonding to the cover sheets.

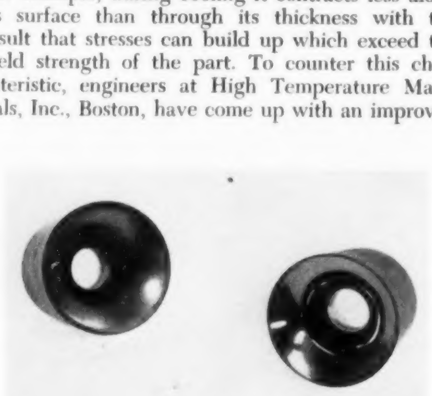
After being rolled, the panel is removed from the frame. With the support wedges in place it can be formed with standard tooling into various shapes, including a hemisphere, without buckling the core. The support wedges are removed by leaching them out with a reagent such as nitric acid.

Progress in Nonmetallic Materials

Pyrolitic graphite, produced by deposition of carbon from a carbon-bearing gas, possesses some unique properties which made it useful in high-temperature applications. Consider its unusual heat conduction properties, for example. In the plane parallel to its surface, pyrolitic graphite is an excellent conductor of heat, but perpendicular to its surface, it is one of the best insulators. When the material is exposed to high temperatures such as experienced in the blast of a rocket, this unique behavior permits it to achieve a temperature gradient of 4000° F. in thickness of only 0.125 in.

But anisotropic behavior has also been the cause of some difficulty with pyrolitic graphite. For example, during cooling it contracts less along its surface than through its thickness with the result that stresses can build up which exceed the yield strength of the part. To counter this characteristic, engineers at High Temperature Materials, Inc., Boston, have come up with an improved grade of pyrolitic graphite which contains boron. Bend strength of the new material at room temperature is said to be about 34,000 psi., some 70% higher than ordinary pyrolitic graphite. Thus, it is better able to resist cracking during cooling and during machining. Like other graphite, the new grade becomes stronger and improves as an insulator as temperature goes up to 5000° F. It can exhibit the 4000° F. temperature gradient across a thickness of only 1/20 in.

Because of its improved properties, the material is expected to be more suitable in applications of ordinary pyrolitic graphite which is now being made into crucibles and boats for the metals and electronics industries, molds and dies for glass making, components for nuclear reactors and parts for high-temperature applications.



Boron Improves Pyrolitic Graphite
Strength and Insulating Properties Are Better Than Those of Ordinary Pyrolitic Graphite

From Here and There

The Census Bureau states that shipments in 1959 of "atomic energy products" manufactured or assembled in privately owned American establishments were valued at \$245,000,000, up nearly 50% over 1958. Principal items were reactor elements (\$54,800,000), heat exchangers (\$27,200,000), vessels and tanks (\$20,000,000), pumps (\$19,500,000), counters (\$16,400,000), and valves (\$14,000,000).

Also included in the estimate is the value of fuel handling and processing equipment, shielding, devices using radioactive isotopes and hot-laboratory equipment. It's fairly big business!

• • • •

An agreement to license a plant for continuous casting of steel has been announced by Babcock & Wilcox Co. The plant will be operated by the Roanoke Electric Steel Corp., Roanoke, Va., on an experimental basis under production conditions. It will produce continuously cast bars ranging from 3 to 6 in. square

Tool Steels in Today's Industry

Greater accuracy in hardening and more freedom from cracking when intricate sections are heat treated account for the increased use of air-hardening tool steels. This point is made by Neil J. Culp, in "Better Air-Hardening Tool Steels" which appears in *Metal Progress* next month as part of a feature on tool steels. The report will also include articles which tell how to overcome distortion and cracking, how hot hardness varies, and describe the advances which high speed steels have made.

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Metal Progress

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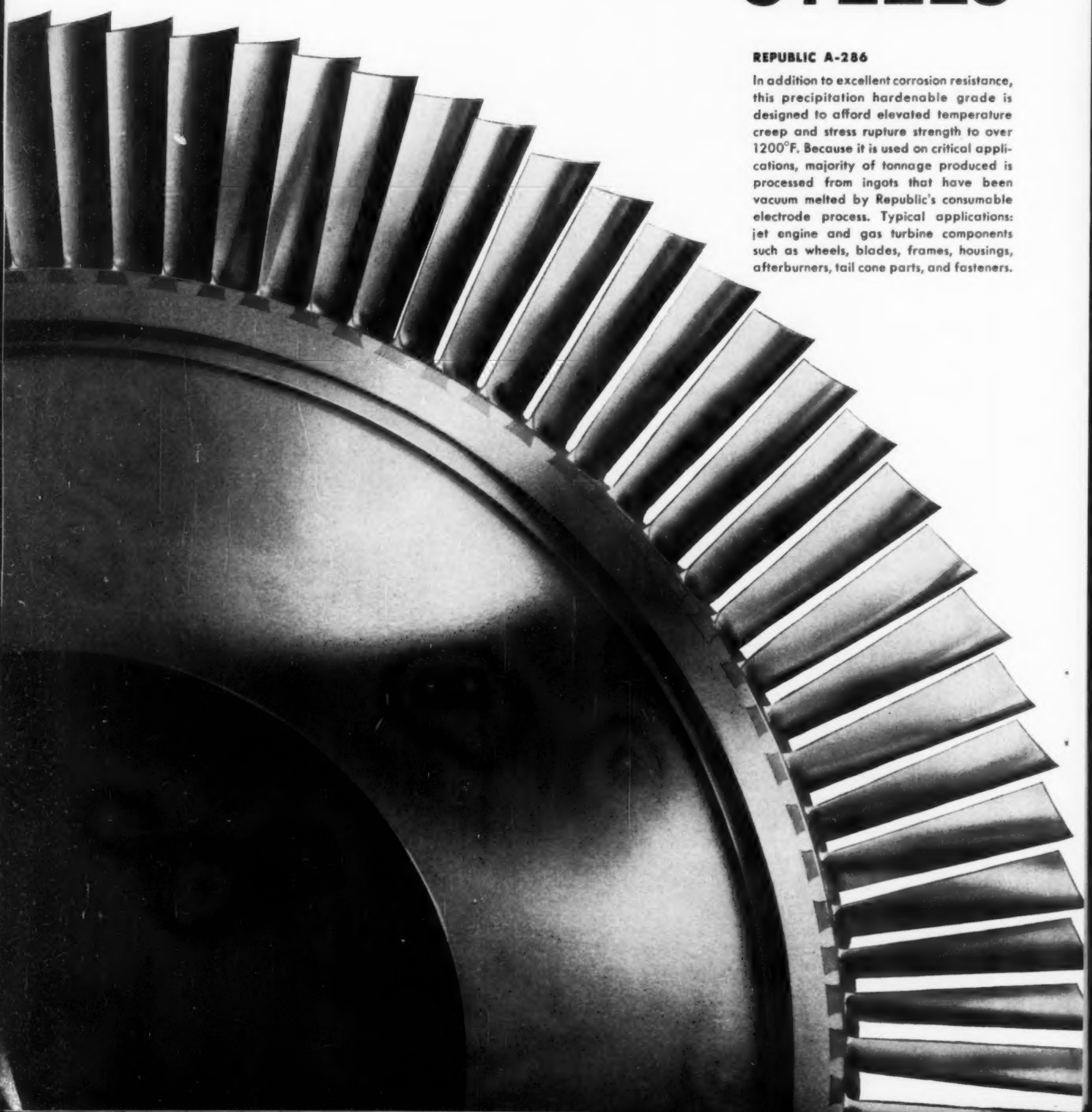
REPUBLIC PH STAINLESS STEELS



REPUBLIC A-286

In addition to excellent corrosion resistance, this precipitation hardenable grade is designed to afford elevated temperature creep and stress rupture strength to over 1200°F. Because it is used on critical applications, majority of tonnage produced is processed from ingots that have been vacuum melted by Republic's consumable electrode process. Typical applications: jet engine and gas turbine components such as wheels, blades, frames, housings, afterburners, tail cone parts, and fasteners.

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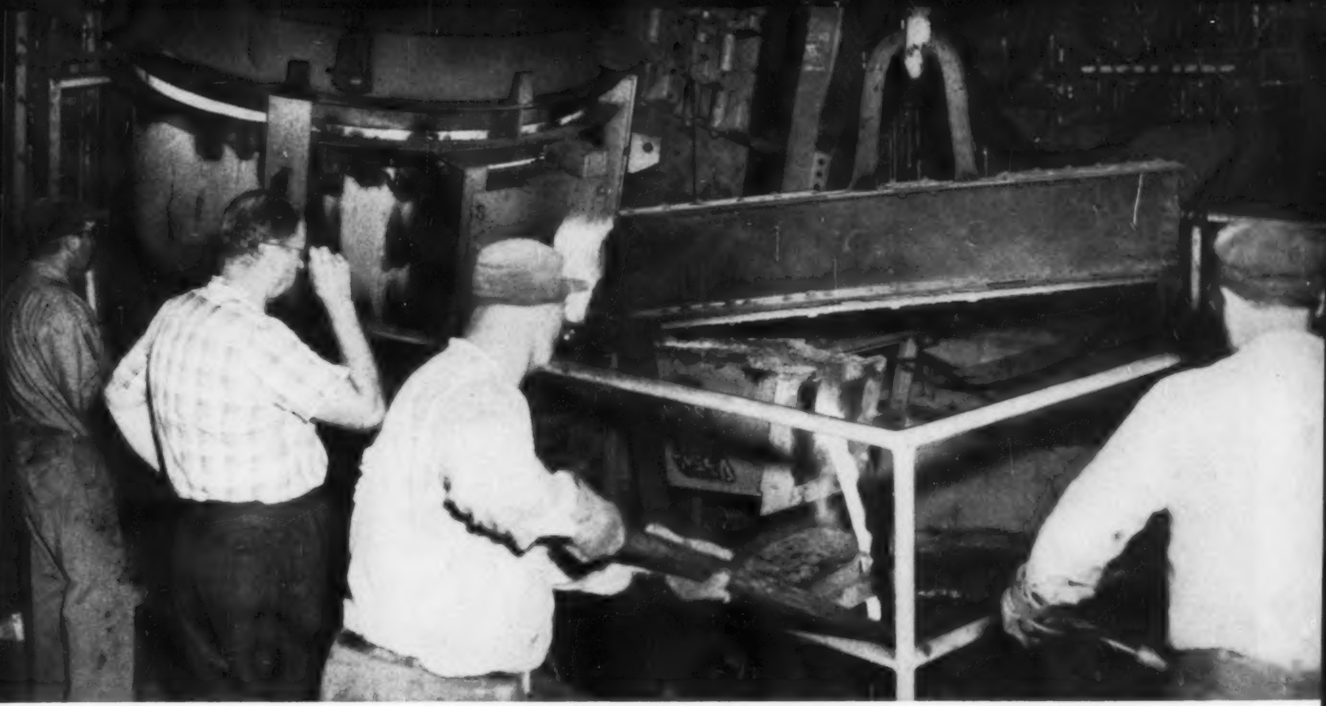


"Electric arc melting gives us improved metallurgical quality at an economic advantage," says Birdsboro Corporation.

This mark tells you a product is made of modern, dependable Steel.

Steel castings provide a wide range of selective materials, both as to chemical analysis and mechanical properties, which are suitable for application in various service and environmental conditions. The recent selection by Birdsboro Corporation of two new electric arc furnaces to replace open hearths and to complement existing arc melting facilities has contributed markedly to diversification of their steel foundry operations to meet these requirements.

Demand has been matched with flexible melting capacity through installation of two Heroult Electric Arc Melting Furnaces:

Shell Size	Capacity	Melting Rate
8-foot	10-ton	2 tons per hour
13.5-foot	30-ton	7 tons per hour

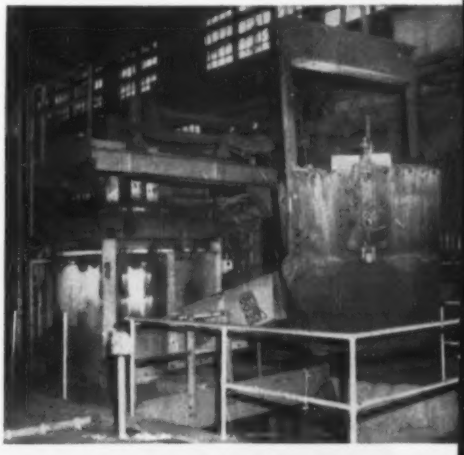
These two furnaces increase total electric melting capacity to 300 tons per day.

Service to customers was the primary requisite in Birdsboro's selection of this equipment. In addition, sales possibilities have increased, quality of metal is superior, alloy recovery is higher, maintenance is reduced, and man-hours per ton is lower. Result—steady improvement of steel melting costs.

American Bridge constructs furnaces for all types of arc melting, in charge capacities to over 200 tons. You can select door-charge or swing roof top-charge types. Your crew can easily maintain a Heroult furnace.

If you're after melting flexibility, increased production, and lower costs, check American Bridge's complete design, construction and installation service.

USS is a registered trademark



General Offices: 525 William Penn Place, Pittsburgh, Pa. Contracting Offices in: Ambridge • Atlanta • Baltimore Birmingham • Boston • Chicago • Cincinnati • Cleveland • Dallas • Denver • Detroit • Elmira • Gary • Harrisburg, Pa. Houston • Los Angeles • Memphis • Minneapolis • New York • Orange, Texas • Philadelphia • Pittsburgh Portland, Oregon • Roanoke • St. Louis • San Francisco • Trenton • United States Steel Export Company, New York

American Bridge Division of United States Steel

USS

Circle 1847 on Page 48-B

Circle 1934 on Page 48-B

introduces the E-beam mark V electron beam evaporator

The Mark V Electron Beam Evaporator is a reasonably priced, highly flexible unit for producing thin metallic and non-metallic films by vapor deposition through electron bombardment heating.

Completely self-contained and free of any radiation hazard, it is an invaluable research and development or limited-production tool for thin-film applications, including micro-miniaturized electronic circuitry, optical filters, semiconductors, magnetic tapes, and countless other components.

Vacuum system, electron gun, power supply and controls are conveniently arranged for maximum accessibility and simplicity of operation and maintenance.

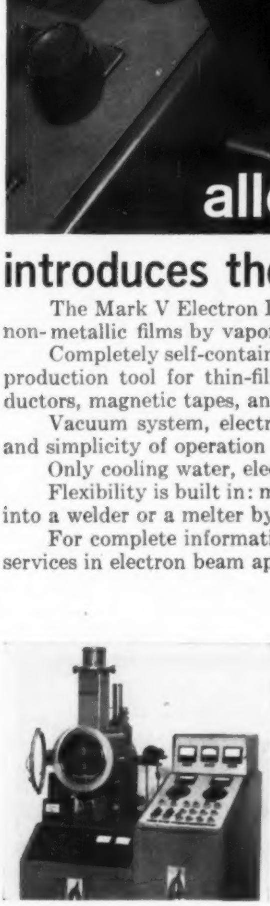
Only cooling water, electrical power, and low pressure air are needed to make the unit completely operative.

Flexibility is built in: modular design allows for interchangeable chambers, permitting the Mark V to be converted into a welder or a melter by substituting a modified chamber.

For complete information on the Mark V evaporator, the Mark VI welder, and Alloyd's engineering and custom services in electron beam applications, just write:

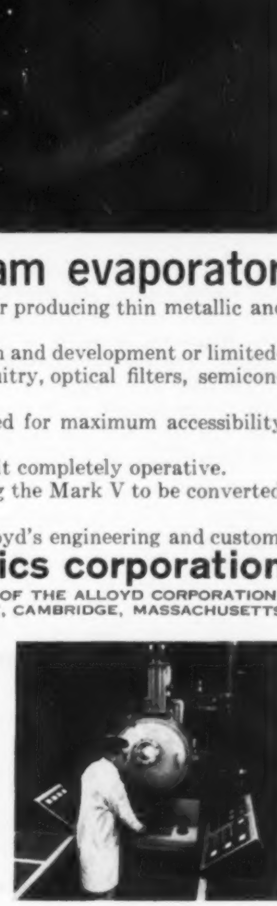
alloyd electronics corporation

AN AFFILIATE OF THE ALLOYD CORPORATION,
37 CAMBRIDGE PARKWAY, CAMBRIDGE, MASSACHUSETTS



Mark VI Electron Beam Welder — for clean, crack-free welds in even the most refractory and reactive metals by electron bombardment. High vacuum eliminates contamination. Ultra-narrow heating zone permits optimum control and precision in handling very thin pieces or welding thin-to-thick sections.

AMEBA — Alloyd Modular Electron Beam Apparatus is part of an advanced, complete facility for thin film evaporation, welding, brazing, melting, and zone refining maintained by Alloyd to meet custom requirements. We also offer engineering, consulting, and research and development services in system design and development. Ask us for complete information.



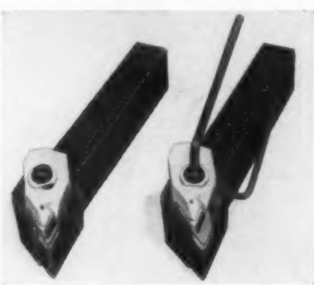
Circle 1935 on Page 48-B

NEW PRODUCTS

Tooling

Disposable Insert Tooling

The versatile "Adjust-O-Breaker" is now available in seven sizes of negative-rake toolholders for all types of



short and medium-run work. The photo illustrates the range of adjustment possible. A change in breaker position is quickly made by loosening the top clamp screw and turning the adjusting screw on the side. The clamp which holds chipbreaker and insert is of strong bridge-type design which bears on the breaker at one end and the tool body at the other. Clamping force is on the flat of the breaker and insert to prevent pull-out of the insert. *General Electric Co.*

For further information circle No. 1587 on literature request card, p. 48B

Heating

Heating Element Alloy

An iron-chromium-aluminum resistance alloy, which gives longer service life at temperatures to 2050° F., is now available in a complete range of wire and ribbon sizes. While the resistivity of "Alloy 750" is somewhat lower than other Fe-Cr-Al alloys, its increase in resistance from room to operating temperature is much greater. This means that fewer "cold" ohms – and fewer feet of Alloy 750 wire – are required to produce the "hot" ohms at operating temperatures. *Hoskins Mfg. Co.*

For further information circle No. 1588 on literature request card, p. 48B

Measures Temperatures to 4000° F.

The "Pyrotron" radiation pyrometer provides a high signal output (60 millivolts) to permit the use of an a-c. type receiver-recorder located up to 500 ft. away. Accuracy is ±1% of the temperature span. The a-c. bridge circuit requires no standardized voltage pre-amplifier, or d-c. to a-c. converter. An optical sighting system provides a visual check of correct alignment and permits

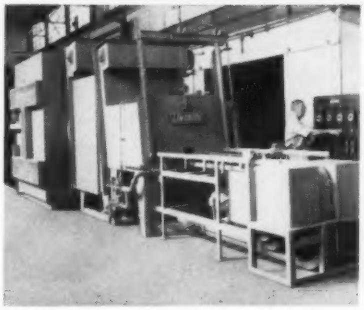
measuring the radiation source to assure that it is of adequate size. *Bailey Meter Co.*

For further information circle No. 1589 on literature request card, p. 48B

Hydrogen Atmosphere Furnace

Capable of a maximum temperature of 2100° F., this automatic electric furnace is used for bright heat treating


KLASSY-KUT
KUT-RATE KLOTHES
BARGAINS
SALE!
GET'EM WHILE THEY LAST!!
WHY PAY MORE?



and brazing of stainless steel and other high-temperature alloys. The equipment features a horizontal cylindrical muffle with an atmosphere lock ahead of the cooling section and a heat exchanger built into the atmosphere quench chamber. *The Lindberg Engineering Co.*
For further information circle No. 1590 on literature request card, p. 48B

Low-Temperature Cabinet

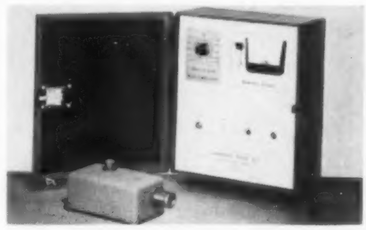
Designed for industrial applications in research, storage, and testing, the "Model SZC-859" low-temperature cabinet needs no liquid coolant; it employs the cascade system to attain

temperatures as low as $-140°$ F. with 70° F. ambient. The unit features 6.5 cu.ft. of storage space and an indicator-controller dial adjustment of temperature; it operates on 230-v., 60-cycle, single phase power.
For further information circle No. 1591

Portable Gas Torch

The portable "High-Blast" torch from *Bryant Industrial Products Corp.* needs no blower for efficient burning —it operates on shop air plus any low-pressure gas (natural, propane or butane). Applications include drying molds and cores, melting nonferrous metals, flame annealing, brazing, and preheating for welding. Available in eight sizes with heat capacities from 40,000 to 3,000,000 Btu. per hr., the flame length varies from 10 in. to 4 ft.
Circle No. 1592 on request card, p. 48B

Radiation Thermometer

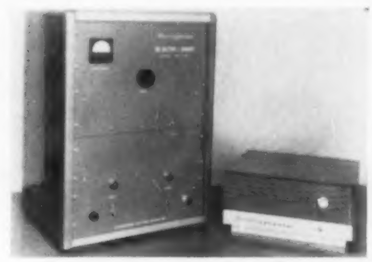


The "Thermodot Model TD-6" radiation thermometer measures and controls temperature (from 210 to 3300° F.) without contact by means of infrared detection. Measurements are continuous and response is rapid (0.3 sec.) and accurate. The instrument can be used in assembly-line production, industrial testing, and automatic control of heat treating or metal fabricating operations. *Radiation Electronics Co.*
For further information circle No. 1593

Finishing

Generator for Ultrasonic Cleaning

Although 50% lighter and 75% smaller than the present tube model, the "solid state" 1-kw. generator (right) is 50% more efficient and operates on 25% less power. No warm-up or tuning is required and an automatic frequency-tracking circuit allows the generator to operate at maximum capacity for efficient cleaning. *Westinghouse Electric Corp.*



For further information circle No. 1594

One-Step Metal Cleaner

Designed to simplify the pre-paint treatment of metal surfaces "Turco W.O. #1" cleans, passivates and

Heavily stressed parts made from tough, hardened 4615/20 nickel steels help this Barber-Colman lathe handle heavy work loads with close tolerances.

Nickel alloy steels safeguard the working accuracy of this Barber-Colman lathe

For sustained high-volume production without loss of accuracy...

...here's where Barber-Colman uses 4615/20 nickel alloy steels for vital components:

All *these* parts are made from AISI 4615 steel (1.8% nickel):

- tailstock spindle
- spindle front cap
- reverse rod bushing
- tailstock binder shaft
- handwheel pinion shaft

And the main headstock spindle is made from AISI 4620, to give this critical component built-in resistance to torsion, fatigue, and frictional wear...

AISI 4615 and 4620 steels, carburized and hardened, provide a hard case for wear resistance, *plus* a tough, strong core to withstand shock-loading. In addition, both possess good resistance to distortion in heat treatment...a positive way to help cut costly finish-machining.

When you order or design machine parts, remember these tough, wear-resisting nickel alloy steels. And for engineering information to help you select the best metal for a particular job, write to INCO, outlining your problem.

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street INCO New York 5, N. Y.

INCO NICKEL

NICKEL MAKES STEEL PERFORM BETTER LONGER

removes corrosion – all in one step. The product can be applied by brushing, spraying, swabbing, or by immersion. Large equipment such as construction machinery, or aircraft, may be effectively cleaned in the field, without dismantling. *Turco Products.*
For further information circle No. 1595 on literature request card, p. 48B

Airless Spray Painting

The *DeVilbiss Co.* is offering a lightweight pump, which makes the "no overspray" advantage of airless spraying available for operations such as industrial maintenance or product

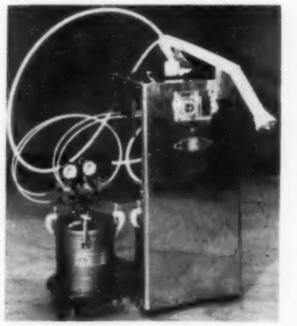
finishing. The pump will handle all conventional paints, when used in conjunction with a standard airless gun fitted with a medium-production cap. The pump will operate with an air compressor as small as 1 hp.
For further information circle No. 1596 on literature request card, p. 48B

Stripable Protective Coating

"Strip-Gard", a clear vinyl coating applied by brushing or dipping, eliminates scratches on polished metal (building panels, auto trim, kitchenware) during fabrication, storage or shipment. Since the coating is flexible, sheet metal can be corrugated, embossed, roll formed, or drawn – in many cases without lubrication. In addition, there is no need for a final clean-up after fabrication or assembly. *American-Marietta Co.*
For further information circle No. 1597 on literature request card, p. 48B

Electrostatic Spray Gun

The "Model 10" spray apparatus can spray-paint articles with conductive or non-conductive coatings, either indoors or outdoors. The coating material is atomized and the microscopic particles are then ionized before spraying to eliminate paint loss. A new model, the "Rainbow Gun", can apply either a yellow, blue, red or white coating – individually or simultaneously. These primary colors can be instantaneously changed to orange,



purple, pink, green, or any other color, because the atomizer can mix the various colors in any proportion as they are supplied to the head. *Ionic Electrostatic Corp.*
For further information circle No. 1598 on literature request card, p. 48B

Welding

Brazing Alloys In New Form

"Nicrobraz S", a mixture of brazing alloy powder in a high-viscosity vehicle, cuts application time by 50%. All Nicrobraz alloys are available in the new form and are applicable wherever powdered materials have been used, such as joining of stainless steel or superalloy components for high-temperature service. An air gun is employed for production jobs

(photo); a manual syringe can be used for development work. *Wall-Colmonoy Corp.*
For further information circle No. 1599 on literature request card, p. 48B

Semi-Automatic Production Welder

Designed to provide the high deposition rates of an automatic process while maintaining the flexibility of manual welding, the "Innershield Squirt Welder" continuously feeds a tubular, self-shielding electrode through a manual welding gun. An M-G set supplies d-c. power for the welding range of 350 to 600 amp.

Amperage control is achieved by varying the wire-feed speed. The control panel contains an electrode

"inch" button, a polarity switch, and an arc voltage control. A 50-lb. coil of Innershield electrode is fed through the hollow welding cable. *Lincoln Electric Co.*
For further information circle No. 1600 on literature request card, p. 48B

Electronic Line Follower

For cutting work of a nonrepetitive nature, the "Aircotron Model J" electronic tracer will follow templates prepared by conventional drafting methods—reducing the cost of templates and of finished work. Stepless cutting speed control and tracing of 90° corners without the need of a corner radii

are provided. The Model J employs a light-sensitive element in the scanning head to follow the template line, which must be maintained between 0.020 and 0.040 in. thick. The tracer, which is not affected by extraneous light, has a cutting range of 5 to 24 ipm. *Air Reduction Sales Co.*
For further information circle No. 1601 on literature request card, p. 48B

Hardsurfacing Electrodes

"Hardalloy 55" is a high-alloy, low-hydrogen electrode (EFeCr-A1) which deposits a hard surface that is resistant to wear under high-stress conditions. Operating on a-c., or

THE LITHIUM REACTOR

CURRENT INFORMATION ON LITHIUM CHEMISTRY AND METALLURGY

HOW LITHIUM IS HELPING EXPAND MODERN METALLURGY

Discovered in 1817, and isolated in metallic form a year later, lithium has achieved prominent use in the metallurgical field only in comparatively recent years, as modern technology has demanded new materials with unusual properties and better performance. The first important application of lithium in metals came in 1918, when it was employed in Germany as an alloying element in Scleron, an aluminum-zinc alloy in which small amounts of lithium were used to improve the characteristics of the base metal and impart greater strength, toughness and hardness.

Starting in the late 1930's, lithium came into use in the degasification of copper castings. At first, a "lithium-copper alloy" was employed, then lithium cartridges — thin walled cylinders of pure copper containing specific weights of metallic lithium. Lithium is now widely used in producing copper free from oxygen and other gases. Approximately 50,000,000 lbs of non-ferrous castings were made by this method in 1955 and the practice is growing.

Serious study of other metallurgical applications of lithium has resulted in a number of developments. Lithium is now being used in the manufacture of self-fluxing alloys for brazing of alloy steels, where it effectively removes any oxides. Lithium also can, under controlled conditions, eliminate the need for fluxes, and in some cases, the use of inert atmospheres as well.

Metals For the Space Age

The present demand for beryllium, titanium, zirconium, thorium and molybdenum — has led to advances in the electrowinning and electrorefining processes for these metals. Lithium salts, when added to the fused salt baths, provide lower-melting mixtures.

Other recent applications of lithium include the development of high-strength lithium-aluminum alloys for the skins of supersonic aircraft, and a lithium-magnesium alloy which shows excellent promise for lightweight armor plate.

To date, only a limited range of lithium's properties as an alloying element have been explored. As further data are assembled, it is expected that other lithium-bearing alloys will be developed for specific uses.

LITHIUM IN BRIEF

New developments involving lithium are constantly appearing in the literature. Each month some will be mentioned here briefly.

A discussion of the electrolytic preparation of rare earth metals notes that certain cerium salts can be electrolyzed in KCl-LiCl and CaF_2-LiF eutectics. Lithium is the reductant for preparation of most rare earths from their fluorides, and has little tendency to alloy with them. (4033)

A study by the AEC reports on the physical and mechanical properties of some aluminum-lithium alloys. High temperature properties are determined for some compositions. (4073)

Investigations into the phase equilibria of systems involving alkali and alkaline-earth metals reveal data on lithium-strontium and lithium-calcium systems. (4077)

A recent patent covers the heat-treatment of magnesium-lithium alloys in hydriding atmospheres for conversion of the lithium to lithium hydride and improvement of the alloys' high temperature strength. (4135)

A new ferromagnetic material has the empirical formula $LiFe_2O_3F$. (4155)

A study of nuclear magnetic resonance intensities in alloys shows that nuclear quadripole effects are prominent in the steady-state magnetic resonances of lithium-magnesium alloys. (4239)

Studies of thermal conductivity of aluminum-lithium alloys show that lithium additions decrease thermal conductivity in a non-uniform manner, with the greatest decrease occurring during the first 2% addition. (4298)

A lithium air-proof brazing alloy was used in construction of the B-58 Hustler, newest bomber of the Strategic Air Command.

BRAZING ALLOYS WITH LITHIUM PROVIDE FASTER, MORE RELIABLE METAL BONDING

With the general trend toward more reliable, less complex methods of joining metals, much research has been performed to develop brazing alloys that can be used for brazing in air without need for additional fluxes or inert atmospheres.

A "self-fluxing, airproof brazing alloy" would simplify brazing production procedures and eliminate the need for external fluxes that may become trapped in the joint.

The alloys that exhibit the most promise in fulfilling this objective contain lithium as an active ingredient. Lithium has a strong reducing action that enables it to protect the surface of the base metal from oxidation and allow the brazing alloy to wet the metal for complete joint penetration.

When combined in the brazing alloy formulation with another reducing element such as boron, the following desirable properties are obtained: (1) An extremely active composition whose ingredients have high affinity for oxygen; (2) Formation of a low-melting protective eutectic of the oxides of lithium and boron when the joint is heated; (3) Excellent fluxing powers and the ability to put even refractory oxides into solution.

Work is now going forward to develop brazing alloys that will incorporate the above characteristics and also possess high corrosion resistance and good homogeneity.

LITHIUM CORPORATION OF AMERICA, INC.

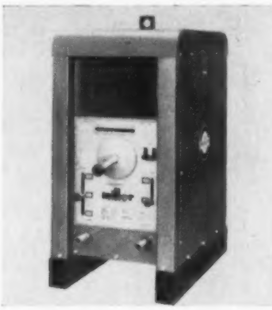
500 FIFTH AVENUE • NEW YORK 36, N. Y.

NEW YORK 36, N. Y. • CLEVELAND 14, OHIO • CHICAGO 1, ILL. • LOS ANGELES 36, CALIF. • BESSEMER CITY, N. C.

d-c. reverse polarity, the electrode has good "out-of-position" characteristics. Deposits retain hardness to 900° F. but cannot be forged or heat treated. Electrode sizes available are 1/8, 5/32, 3/16, and 1/4 in. in standard 14-in. lengths. *McKay Co.*
Circle No. 1602 on request card, p. 48B

AC-DC Welder

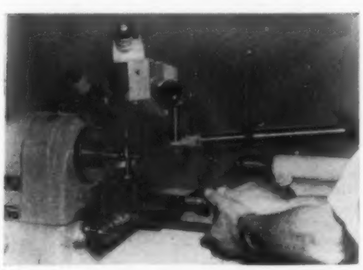
The "Series MD" welder features continuous current control, straight or reverse polarity (d-c.), open circuit voltage of 80 v. (a-c. or d-c.), and a choice of two wide welding current ranges for each section. Offered in 300, 400 and 500 amp. sizes, every model contains a semi-metallic rectifier and has forced-draft ventilation for long life. *Miller Electric Mfg. Co.*



For further information circle No. 1603

Testing

Measurement of Small Parts



A utility microscope offered by *American Optical Co.* provides low-power magnification, a wide field of view and a fixed, long working distance of 4 in. – important features when inspecting or measuring small parts or critical work. It can be attached to any machine or fixture and is ideal for observing gross surface characteristics, blowholes, cracks or flaws. Two models are available: One provides 20 × magnification; the other offers a choice of three magnifications: 10×, 20× and 30×.
For further information circle No. 1604 on literature request card, p. 48B

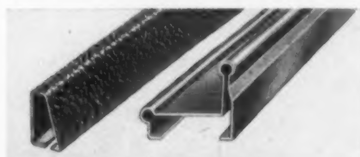
Industrial X-Ray Paper

"Cawo" industrial x-ray paper costs about half as much as standard film used in nondestructive testing of mass-produced items such as electronic assemblies or weldments. Sharp contrast images on Cawo paper can be inspected directly without special viewing devices because it is a fog-free glossy print – not a film. *Picker X-Ray Corp.*
For further information circle No. 1605 on literature request card, p. 48B

Parts

Roll-Formed Shapes

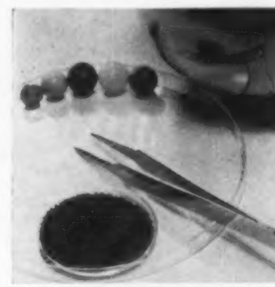
The *Roll Formed Products Co.* is producing vinyl-clad metal shapes, such as the trim section (left) and rack slide (right) with the vinyl cap (added after roll forming). Punching and notching operations can be performed without marring the finish. Channels, angles, and T-sections, as well as lock-seam and butt-seam tubing, are available with smooth or textured finishes in a wide range of colors.



For further information circle No. 1606 on literature request card, p. 48B

Special Precision Balls

Precision balls are now produced from many special materials, such as boron carbide, titanium diboride, tantalum, titanium carbide, ferrites, and high-density alumina. This greatly extends the range of applications involving temperature and load extremes, corrosion resistance, magnetic or dielectric properties, or controlled density. For research and development, balls of high-purity metals can be furnished in a wide range of sizes, tolerances, and surface finishes. *Industrial Tectonics, Inc.*



For further information circle No. 1607 on literature request card, p. 48B

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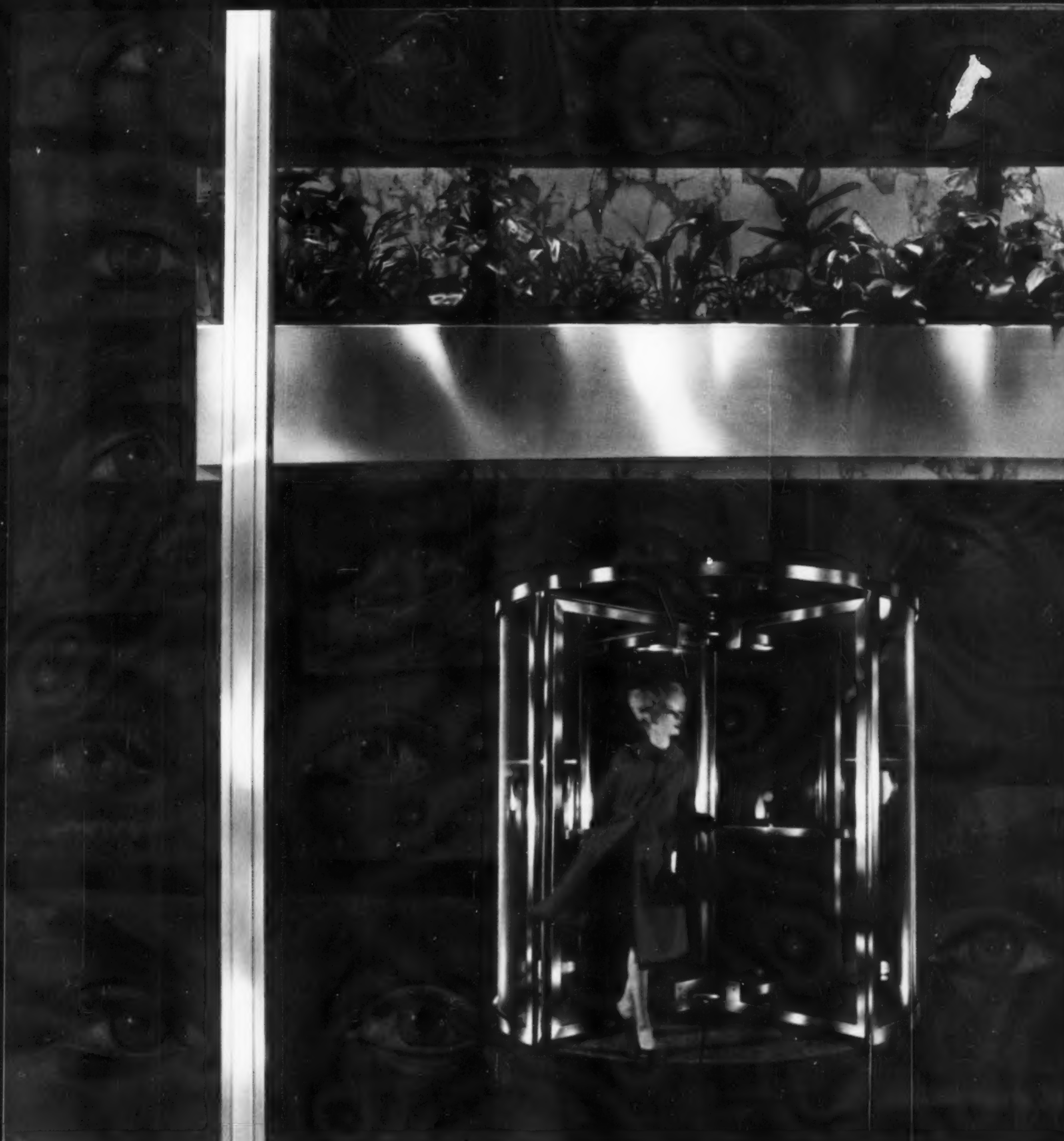
Circle 1857 on Page 48-B

Circle 1910 on Page 48-B



Huntington Alloys

Inconel alloy's unusual combination of properties can solve many metal problems

Outstanding corrosion resistance...good high and low temperature properties... easy fabrication and good weldability...plus other important properties make Inconel* nickel-chromium alloy ideal for many applications.

Outstanding corrosion resistance

Inconel alloy provides outstanding resistance to a great variety of corrosives—including distilled and fresh water, the majority of neutral and alkaline salts, acid salts, most oxidizing acids, and oxidizing acid salts. Inconel alloy also resists corrosion by organic acids and compounds, gases and many other highly corrosive environments—at normal or extreme temperatures.

Excellent resistance to stress-corrosion cracking

Stress-corrosion cracking is often a cause of premature failure in equipment used to handle solutions containing chlorides. Inconel alloy solves this problem—resists stress-corrosion cracking, intergranular corrosion and other forms of attack, even when subjected to applied stresses, welding stresses, alternate wetting and drying, and vapor phase exposure.

Excellent high and low temperature properties

Inconel alloy—long-recognized as an excellent high temperature alloy with outstanding resistance to common heat treating atmospheres—also has excellent properties at sub-zero temperatures. As temperatures decrease, Inconel alloy's strength *increases* considerably without appreciable change in ductility or toughness. These important properties make Inconel alloy excellent for handling cryogenic fluids.

Easy weldability and fabrication

Inconel alloy is unusual in that it has high corrosion and heat resistance *and* is easy to weld and fabricate. Inconel alloy can be easily joined by conventional welding and brazing. And in hot working, Inconel alloy can be worked with proper procedures to shapes regularly forgeable in steel. This permits any practical design with Inconel alloy. (Recommended working and fabricating procedures are available in detail on request, from Huntington Alloy Products Division.)

Above, wrought Inconel alloy shell protects graphite anodes in 1400° F bath of molten fluoborate and fused potassium chloride. Inconel alloy was chosen because of outstanding resistance to heat, thermal shock, and stress-corrosion.

What are your metal problems?

Can you use an alloy that combines outstanding corrosion resistance, good high and low temperature properties, easy fabricating and good weldability? For detailed information on how Inconel alloy meets these and other requirements, write for Technical Bulletin T-7: Engineering Properties of Inconel.

*Inco trademark

INCO

HUNTINGTON ALLOY PRODUCTS DIVISION
The International Nickel Company, Inc.
Huntington 17, West Virginia

INCONEL®

Circle 1858 on Page 48-B

Circle 1859 on Page 48-B

Action When Our Customers Need it Most!

Shipped on an interim basis, this high frequency induction furnace got an Inductotherm customer back into business less than 24 hours after an unfortunate pouring accident temporarily put his old unit out of commission. Such service is part of Inducto's concept of doing business . . . an obligation we feel to keep every customer's furnaces pouring on schedule regardless of emergencies. Should trouble develop, Inductotherm usually has a trained engineer on the spot in a matter of hours. Emergency orders are stamped for special priority . . . replacement parts shipped immediately from Inducto's complete inventory—all to assure that your work will be started at once and continued into overtime if necessary.

But service is only one of the overall cost-saving benefits Inductotherm offers. For a look at the entire story, ask to have an Inducto engineer call. Inductotherm Corporation, 412 Illinois Ave., Delanco, N. J.

INDUCTOTHERM

Circle 1860 on Page 48-B

NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERAUTRE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LI

METAL PROGRESS

NEW LITERATURE

Steel

1610. Special Tool Steels
Three data sheets describe characteristics and typical applications of five tool steels. Instructions for forging, annealing, quenching and tempering are included. *Heppenstall Co.*

1611. PH Stainless
Armco Steel Corp. will send data on 17-4PH stainless steel. Stronger than Type 416; as corrosion resistant as 18-8 stainless steel.

1612. Alloy Steel Booklet
"Quick Facts About Alloy Steels" published by *Bethlehem Steel Co.* Elementary information on steel heat treatment, properties, and microstructures.

1613. Property Charts
Wallace Barnes Steel Div. has published "Physical Property Charts" on properties and formability of tempered steel.

1614. Cryogenic Service
27-p. booklet "Steels for the Containment of Liquefied Gas" has been issued by *International Nickel Co.*

1615. "Carbon and Graphite News"
8-p. publication features the rapidly expanding role of stainless steel in the architectural market. *National Carbon Co.*

1616. Type 304 Stainless
For the corrosive conditions and high temperatures found in nuclear applications specify Type 304 stainless plate. Get brochure "Producing Stainless Steels Exclusively" from *G. O. Carlson Inc.*

1617. Spring Steels
44-p. catalog-stock list sets forth the details on all grades and sizes of specialty spring steels. *Uddeholm Co. of America*

1618. PH Stainless Steels
These steels offer adequate strength and better corrosion resistance than the hardenable grades of chromium stainless. Details from *Republic Steel Corp.*

1619. High-Strength Steel
Pamphlet from *Great Lakes Steel Corp.* sets forth details on "N-A-Xtra" high-strength steels — to cut dead weight and stretch payload capacity.

Nonferrous

1620. Impact Extrusions
Alcoa has published a 34-page brochure on impact extrusions entitled "Metal in Motion" which details applications and savings possible.

1621. Stock Catalog
290 pages of stock information on nonferrous and stainless steel mill products. Latest government and society specifications included. Data from *Meier Brass & Aluminum Co.*

1622. Rare-Earth Metals
The *Lunex Co.* will send pamphlet describing the properties of high-purity rare-earth metals including lanthanum, yttrium, and gadolinium.

1623. Conductivity Rating
8-p. bulletin provides a rapid check list for electrical conductivity ratings of 56 copper alloys. *Bridgeport Brass Co.*

1624. Rare Earths
Vitro Chemical Co. has published a pamphlet on rare earths, including scandium and yttrium.

1625. W and Mo
Information on tungsten and molybdenum ingots and billets from *Sylvania Electric Products, Inc.*

1626. Deep Drawing Magnesium
The *Dow Metal Products Co.* will send reprint discussing the deep drawing of magnesium for containers, cases and housings.

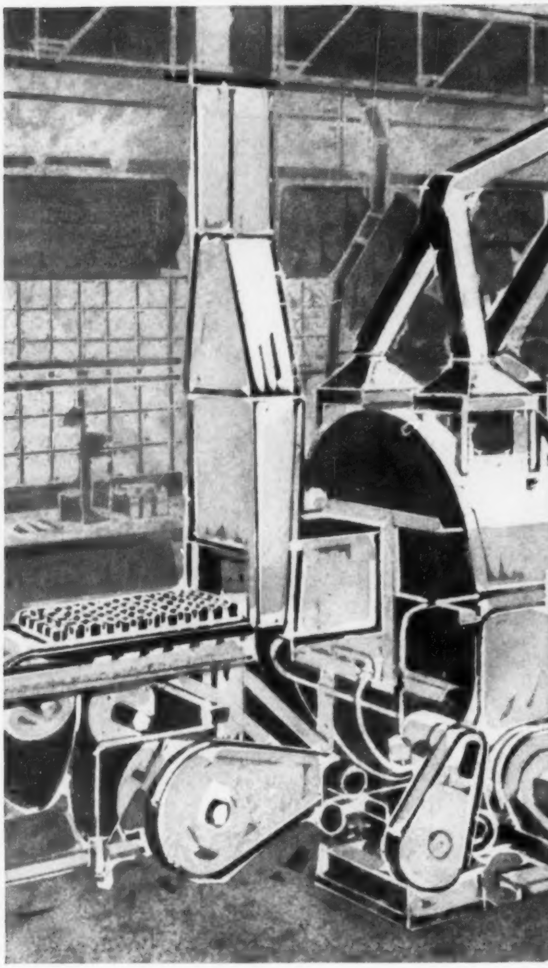
1627. Zirconium-Copper
Leaflet from *Amco Div.* discusses "Amzirc", a zirconium-copper alloy that combines high conductivity and good resistance to thermal impact.

1628. Drawn Brass Parts
Anaconda American Brass Co. has released bulletin B-39 which shows how to cut polishing costs and produce stronger parts with "Formbrite", a fine grain drawing brass.

1629. Bronze Plate
Bulletin from *Ampco Metal Inc.* on large sizes of bronze plate for corrosion and abrasion resistance or mechanical service applications.

Circle appropriate number on Reply Card, p. 48-B

NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERAUTRE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERAUTRE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITERATURE • NEW LITE



The most precise temperature control of its kind at the best price!

$150

R7086 POTENTIOMETER CONTROLLER

This transistorized Potentiometer Controller is available for ranges up to +3000°F. The sensitivity of the controller is 120 microvolts irrespective of span. Time proportioning standard at no extra cost. Available with on-off or 2-positioning. Other features include illuminated dial, flashing lights to indicate when temperature is at "set" point, and an 8" scale for easy setting. Thermocouple burn-out protection inherent in design. Controllers can be surface or flush mounted. Other models with centigrade scales are also available.

Honeywell

H *First in Control*

SINCE 1885

HONEYWELL INTERNATIONAL
Sales and service offices in all principal cities of the world. Manufacturing in the United States, United Kingdom, Canada, Netherlands, Germany, France, Japan.

Circle 1861 on Page 48-B

1630. Beryllium Products
Bulletin from *Beryllium Corp.* describes facilities for the production and fabrication of beryllium products, also research and development.

1631. Selection Chart
Seymour Manufacturing Co. is offering an "Alloy Selection Chart" for nickel silver, phosphor bronze, brass, copper, and stainless steel.

1632. Ti-8Al-1Mo-1V Alloy
12-p. data memorandum outlines forging and heat treat procedures for the alloy and includes discussion of creep stability and fatigue properties. *Titanium Metals Corp. of America.*

1633. Machining Aluminum
104-p. booklet presents machining data for aluminum part production on automatic screw machines. *Kaiser Aluminum.*

1634. Titanium Alloy Tubing
Data memorandum "Titanium and Titanium Alloy Tubing" presents information on heat treatment, welding, and application. *Superior Tube Co.*

1635. Aluminum Casting Alloys
Aluminum Co. of America has issued 12-p. brochure which gives information on composition, properties, and characteristics of casting alloys.

Materials

1639. Advanced Materials
Carborundum's 8-p. pamphlet "Materials For Advanced Technology" is a data-packed roundup of 12 new products for applications involving resistance to abrasion, chemicals, corrosion, nuclear radiation or high temperatures.

1640. Superalloy Forgings
Brochure on superalloy forgings — Waspaloy, René 41, Astroloy, Udimet 500, and M-252. *Wyman-Gordon Co.*

1641. Refractory Grains
Catalog from *Norton Co.* describes a wide range of refractory materials. Physical, chemical, and electrical properties of Al_2O_3, MgO, boron carbide, and fused zirconia.

1642. "Powder Metallurgy"
Quarterly publication of the *Metal Powder Industries Federation* (spring-summer 1960) features case histories of electrical applications for powder metallurgy parts.

1643. Service to 2300° F.
Brochure from *Electro-Alloys Div.* on "Supertherm", a 26% chromium, 35% nickel alloy for service in the 1800 to 2300° F. range.

1644. Chromallizing
Bulletin AC from *Chromalloy Corp.* describes the chromallizing process — diffusing chromium and other elements into the surface to provide an alloy case that can't peel or flake.

1645. Heat-Resistant Castings
The *International Nickel Co.* offers booklet "Heat Resistant Castings, Corrosion Resistant Castings . . . Their Engineering Properties and Applications".

1646. Diffusion Furnace Tubes
McDanel Refractory Porcelain Co. has issued pamphlet containing data on mullite or alumina impervious ceramic tubes for high temperature (3000° F.) atmosphere or vacuum furnaces.

1647. For 5500° F. Service
Literature from *Sylvania Electric Products* sets forth the facts on tungsten or molybdenum ingots up to 10 in. in diameter and up to 4 ft. in length.

1648. Silicon Carbide
The *Carborundum Co.* will send literature on a refractory material — silicon carbide — that resists high temperatures, corrosion and thermal shock.

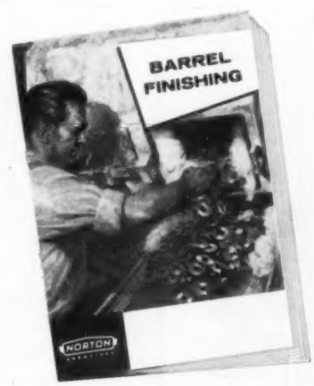
Tooling

1649. Toolsteel Guide
A "Steelector" booklet from *Allegheny Ludlum* gives complete data on line of toolsteels . . . mechanical property and heat treating information included.

1650. Chemical Milling
Eastman Kodak Co. has a brochure which presents information on "Metal-Etch Resist." It speeds up and simplifies chemical milling operations.

1638. Barrel Finishing

Contents of this 96-p. booklet include descriptions of the various barrel finishing processes and equipment, recommendations on optimum abrasive shapes and sizes, case histories of actual ap-



plications, discussions of compounds and their effects, and a section devoted to practical suggestions on operating procedures. *Norton Co.*

1651. Molybdenum Disulphide
24-p. Bulletin 124 discusses the theory and practice of lubrication by solids, including advantages of using molybdenum disulphide solid lubricants. *Alpha-Molykote Corp.*

1652. Toolsteel Heat Treatment
Bethlehem Steel Co. has complete details on short cycle hardening and nitriding of high-carbon, high-chromium toolsteels.

1653. Toolsteel Comparison
Bethlehem Steel Co. has published a 16-p. booklet comparing the properties of four outstanding tool steels—A-4, D-2, A-2, and O-1.

1654. High-Speed Steels
Data sheets from *Vanadium-Alloys Steel Co.* discuss applications—abrasion, impact, high temperature—for various grades of high-speed steel.

1655. Lubricant Coatings
Data sheets from *Acheson Colloids Co.* contain information on "TFE" coatings (tetrafluoroethylene film lubricant) which are applied by spraying to minimize sliding friction at widely varying temperatures.

1656. Ceramic Tools
28-p. fact file presents property data on "Stupalox" ceramic cutting tools plus specifications on throwaway inserts, heavy-duty button inserts, single-point tools, and tool holders. *Carborundum Co.*

1657. Belt Grinder
Eastern Machine Screw Corp. has published Catalog No. 100 on the "Loungway Rise & Fall Abrasive Belt Grinder".

1658. Rolling Mills
Leaflet describes facilities for building and installing complete rolling mill for processing wide strip. *Demag Aktiengesellschaft.*

1659. Graphite Lubricants
A wealth of information for every user of lubricants and protective coatings is contained in handy application chart from *Grafo Colloids Corp.*

1660. Steel Forgings
Bulletin 400 illustrates a wide variety of custom forgings and many of the facilities for producing them at *A. Finkl & Sons Co.*

1661. Roll Forming
88-p. illustrated booklet discusses cold roll-forming equipment, processes and products. *The Yoder Co.*

1662. Rotary Swaging
For a complete guide to rotary swaging plus data on the "Fenn" line of swaging machines, write for Catalog SM-60. *Fenn Mfg. Co.*

1663. Forging and Forming
General Dynamic Corp. has published information on the "Dynapak Model 1220", an efficient dependable high-energy-rate forming machine.

Heating

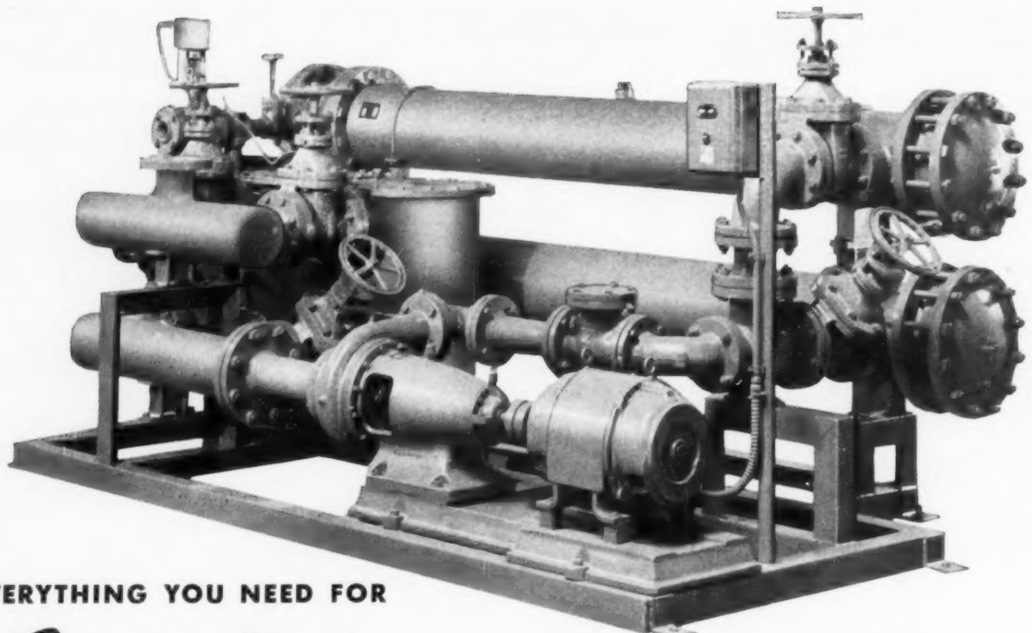
1664. Thermal Fatigue
Electro-Alloys Div. has published "The Mechanism of Thermal Fatigue" by H. S. Avery.

1665. Fluidized Bed Heat Treating
4-p. Bulletin GED-4306 describes fluidized bed heat treating equipment for annealing, normalizing, solutioning, aging, hardening, quenching and isothermal transforming. Up to 85% reduction in heating time. *General Electric Co.*

1666. Gas Burners
Bulletin H-42 tells about "Series ZB" nozzle-mixing burners in firing capacities from 60,000 to 14,500,000 Btu. per hr. *Eclipse Fuel Engineering Co.*

1667. Muffle Furnace
Sunbeam Equipment Corp. has issued bulletin which outlines advantages and features of a conveyor muffle furnace for continuous bright copper brazing, bright

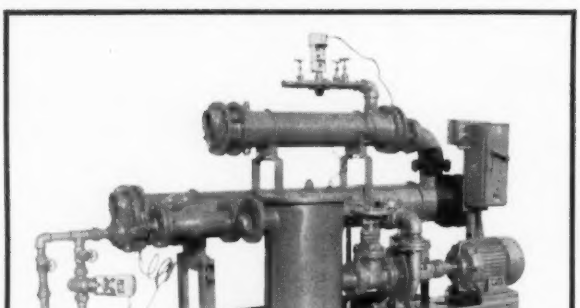
To request any item listed, circle appropriate number on Reply Card, p. 48-B



EVERYTHING YOU NEED FOR

Controlled QUENCH OIL COOLING

...EITHER COMPONENT PARTS OR SELF-CONTAINED UNITS



BOTH HEATS AND COOLS QUENCH OIL

This typical B&G self-contained unit, as installed in automotive plant, both heats and cools quench oil to definite temperature specifications.

A B&G Self-Contained Oil Quenching System, factory-engineered and factory-assembled, avoids assembly errors, saves labor costs and can easily be moved if plant layout so demands. Your only responsibility, once the unit is delivered, is to place it in position and connect it to the quench tank and water lines. Or, if preferred, component parts can be furnished for assembly on the job.

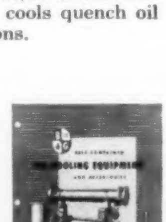
This system circulates oil from the quench tank, cools and strains it, and pumps it back at a rate which keeps oil at the right temperature throughout the quench period. Every batch is quenched under identical conditions, hence every batch emerges identical in quality.

With a B&G Oil Quenching System, quenching is automatically controlled and results are predictable. You cut losses resulting from excessive rejects and realize a substantial "inside profit."

B&G Quench Tanks

Properly designed to induce maximum turbulence in the quench oil, B&G Quench Tanks are available in standard models or can be built to meet any specific quenching requirement.

Send for this combined Catalog and Simplified Selection Manual for B&G Self-Contained Quench Oil Coolers.



B & G

Hydro-Flo®

OIL QUENCHING SYSTEMS

BELL & GOSSETT COMPANY

Dept. GQ-16, Morton Grove, Illinois

Canadian Licensee: S. A. Armstrong Ltd., 1400 O'Connor Drive, Toronto 16, Ont.

Circle 1862 on Page 48-B

annealing and bright hardening of stainless steel.

1668. Stress Relieving
Bulletin D-61 "Controlled Atmosphere Tempering Units" from *Ipsen Industries* describes furnaces for atmosphere tempering, annealing and stress relieving.

1669. Martempering Oils
"Sun Marquenching" oils can be used safely for control of martempering at temperatures up to 400° F. *Sun Oil Co.*

1670. Tube Furnaces
Pereny Equipment Co. has issued leaflet on a "Pereco" carbon resistor tube furnace. Rapid heat-up to 5000° F. with precise control.

1671. Heat Treating Fixtures
Catalog 61 describes baskets, trays, fixtures, carburizing boxes, pots, retorts and furnace parts for heat processing operations. *Stanwood Corp.*

1672. Annealing Strip
Bulletin 128 details the advantages of high-velocity recirculating-type ovens for atmosphere annealing of coiled aluminum strip. *W. S. Rockwell Co.*

1673. Refrigeration Systems
Data sheet and catalog give full information on *Harris Mfg. Co.* "Cascade" refrigeration systems for low-temperature industrial uses.

1674. Induction Heating Equipment
56-p. catalog reviews line of "Ther-Monic" induction heating equipment for hardening, brazing, soldering, forging, annealing, melting, sintering, welding, refining and crystal growing. *Induction Heating Corp.*

1675. "Heat Treat Review"
Volume 12 No. 1 features an article on deep-drawn ferrous and nonferrous metal parts. *Surface Combustion Div.*

1676. Toolsteel Furnaces
Catalog 10-F describes "Diamond Block" atmosphere furnaces for heat treating high-carbon high-chromium, air hardening and high-speed toolsteels. *The Sentry Furnace Co.*

1677. Furnace Tubes
The *Pressed Steel Co.* has published brochure on furnace tubes fabricated from sheet for added tube life and reduced burnout.

1678. Heat Treating Furnaces
Catalog 106-A from *Ajax Electric Co.* describes line of gas-fired heat treating and melting furnaces.

1679. Continuous Annealing
Bright anneal trim stock and other stainless strip to a durable mirror finish without chromium depletion. Get the facts from *Electric Furnace Co.*

1680. Heat Exchangers
To improve heat treating, control quench temperatures with an "Aero" heat exchanger. Bulletin 120 and 132 from *Niagara Blower Co.*

1681. Low-Temperature Cabinets
Folder from *Revco Inc.* on ultra-low temperature cabinets (to −140° F.) for research and processing applications.

1682. Heat Treating Salts
Eliminate scaling and decarburization in heat treating without special atmospheres — through the use of "Aeroheat" salt baths. Details from *American Cyanamid Co.*

1683. Induction Heating Units
Pamphlet from *Lepel High Frequency Laboratories* explains high-frequency induction heating equipment, a practical and efficient source of heat for many industrial applications.

1684. Gas Burners
Brochure from *Charles A. Hones Inc.* reviews line of "Buzzer" burners which need no blowers, power or auxiliary equipment to effect combustion; simply connect to available gas supply.

1685. Thermocouple Components
Catalog G100-3 contains complete details on thermocouple components — wires, insulators, protecting tubes, heads, blocks, connectors for any application. *Minneapolis-Honeywell.*

1686. Rotary Carburizers
For positive cost reduction and product improvement investigate rotary carburizers for deep case carburizing and light case hardening. Pamphlet MP607 from *American Gas Furnace Co.*

1687. Environmental Chamber
Webber Mfg. Co. will send 36-p. brochure on environmental chambers and low-temperature freezers in a wide range of sizes and temperature ranges.

1688. Thermocouple Alloys
Hoskins Mfg. Co. has published a basic guide to accurate temperature measurement. It presents data on the entire family of Chromel-Alumel thermocouple alloys.

1689. Temperature Crayons
"Tempilstiks" are used for determining temperatures in welding, metalworking, heat treating and other heat processing operations. For more informationn contact *Tempil Corp.*

1690. Heat Treating Ovens
Young Brothers Co. will send Bulletin 157 which presents information on batch and conveyor ovens for accurate dependable low-cost heat treating.

1691. Radiant Tubes
General Alloys Co. will send leaflet explaining wrought-cast radiant tubes which give consistent long life.

1692. Sintering Stainless
Whether working with cermets, ceramics, refractory metals, or stainless steel powder compacts, Hayes has the right furnace and the right atmosphere to produce optimum results. Bulletin from *C. I. Hayes, Inc.*

1693. Silicon Carbide Elements
Brochure from *Carborundum* illustrates many advantages in heating with "Globar" silicon carbide elements; temperatures from 1400 to 2800° F.

1694. Salt Baths
E. F. Houghton & Co. has published a leaflet explaining salt baths for carburizing, hardening, annealing, tempering, quenching and nitriding.

1695. Bright Hardening
Bulletin D100A from *Hevi-Duty Electric Co.* details the advantages of "Clean-Line" heat treat furnaces for carbonitriding, carburizing, hardening or annealing.

1696. Mesh-Belt Furnace
Lindberg Engineering Co. will supply you with literature on a continuous furnace with a temperature range of 1300 to 2100° F. and a production capacity of 500 lb. per hr.

1697. Gas Alloying
Get the details on the revolutionary "Open-Coil" process of gas alloying. Brochure OC-960 from *Lee Wilson Engineering Co.*

1698. Foil Annealing
Pamphlet SC-182 explains power convection furnaces which provide uniformity of product at lower cost. *Surface Combustion Div.*

Circle appropriate number on Reply Card, p. 48-B

1699. Sintering Furnace
Bulletin MSF-361 contains information on a mesh-belt furnace for sintering ferrous parts; maximum temperature is 2050° F. *Harper Electric Furnace Corp.*

Finishing

1700. Rust Remover
Data Sheet 3503 presents information on a product that removes rust, gives an iron phosphate coating and cleans light soil. *E. F. Houghton & Co.*

1701. Spray Nozzles
Bulletin 106 from *Spraying Systems Co.* describes complete line of spray nozzles and accessories for washing, rinsing and coating applications in the metal finishing field.

1702. Foamed Solvents
4-p. pamphlet discusses new techniques for cleaning industrial equipment utilizing lightweight foamed solvents for greater efficiency and economy. *The Dow Chemical Co.*

1703. Surface Conditioner
Oakite Products, Inc. has more than 30 materials guaranteed to properly condition aluminum for welding, painting, forming or etching.

1704. Barrel Plating Equipment
161-p. brochure from *Udylite Corp.* describes both manual and automatic barrel plating equipment.

1705. Dry Acid Cleaner
DuBois Chemicals, Inc. has published folder on "Super Di-Ca," a dry acid cleaning compound based on sulfamic acid which is a safer and better acid cleaner.

1706. Low-Firing Porcelain Enamels
Lead Industries Association will send 4-p. data sheet on porcelain enamels for steel. Firing temperatures are 500° F. below conventional enamels.

1707. Protective Coating
Brochure discusses "Permaspray," a sprayable or brushable furan resin which is used as a maintenance or engineering protective coating against corrosion. *Permaspray Mfg. Corp.*

1708. Nickel Stripper
3-p. Data Sheet No. 116 describes "Metex Nickel Stripper BR," a dry powder for immersion stripping of nickel from brass and copper. *MacDermid Inc.*

1709. Spray Cleaner
The *Diversey Corp.* will send information on "Diverfos F-72," a spray cleaner and phosphatizer used as a paint base or for protection against corrosion on iron, steel and other ferrous alloys.

1710. Detail Etching
4-p. leaflet details the properties and advantages of "Resist-etch," which positively blocks off unwanted electroplate and permits pattern lines 0.005 in. wide and 0.005 in. apart. *The Meaker Co.*

1711. Ultrasonic Degreasing
8-p. catalog presents ultrasonic cleaning applications and equipment made by *Phillips Mfg. Co.*

1712. Soak Cleaner
Oakite Products, Inc. will send information on "Oakite HD 126," a cleaner designed to remove heavy soil by immersion. Safe on steel, brass, and magnesium.

1713. Gold Alloy Plating
Sel-Rex Corp. has issued a pamphlet containing case histories and application data on a bright gold alloy "S-42" which improves contact performance in corrosive atmospheres.

1714. Conversion Coatings
Allied Research Products has released a technical data file on "Iridite" chromate conversion coatings for surface protection of aluminum and magnesium.

1715. Nickel Plating
General American Transportation Corp. offers technical details on the "Kanigen" process for chemical nickel-alloy plating. It produces a uniform thickness of coating regardless of part contour.

Welding

1716. Plasma Spraying
Folder entitled "Plasma Bond Spraying Service" describes applications and fabrication techniques for metallic-ceramic coatings. *Thermal Dynamics Corp.*

1717. Electron Beam Welding
The *NRC Equipment Corp.* will send information on electron beam welding, to help solve your tough welding problems.

1718. Plasma Coating
12-p. booklet illustrates the plasma coating process, and presents properties and uses of coatings. *Plasmatech Div.*

1719. Structural Adhesives
Brochure discusses "Lefkoweld" adhesives for bonding metal, ceramics, glass, wood, plastics and hard rubber. *Leffingwell Chemical Co.*

1720. Clad Metals
Bulletin Z-106 explains solder-clad metals for semiconductor and other applications. *Accurate Specialties Co.*

1721. Brazing Alloys
Data sheet contains information on "Nicrobraze 160," a brazing alloy for joining stainless and other high-temperature alloys. *Wall Colmonoy Corp.*

1722. Adhesive Specifications
Minnesota Mining and Mfg. Co. has published 54-p. compilation listing U.S. Government specifications for adhesives, coatings and sealers.

1723. Silver Brazing
Fusion Engineering Co. has prepared 4-p. pamphlet on automatic soft soldering and silver brazing operations.

1724. Resistance Welders
8-p. Brochure I-60 will be sent to you by the *Federal Machine and Welder Co.* This manual contains suggestions on correct operation and maintenance of welders.

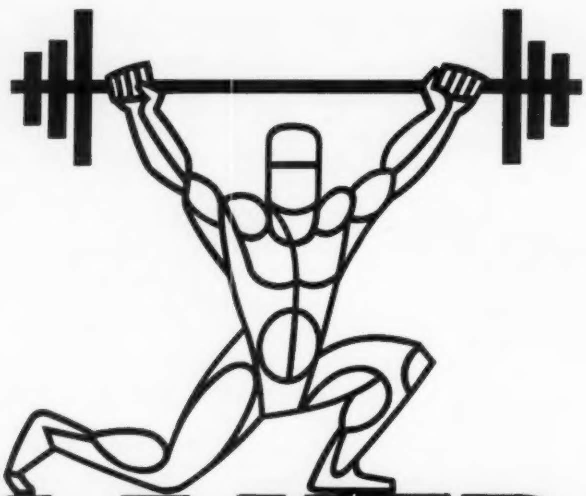
1725. Six-In-One Arc Gun
This gun serves as a spot welder, stud welder, tack welder, button welder, hole burner and riveter. Details from *Beeco Mfg. Co.*

1726. DC Welder
The "Sureweld" DRC-33 welder offers continuous voltage and slope adjustment. *National Cylinder Gas Div.* will send bulletin.

1727. Welding Alloy Wall Chart
Welding, brazing and soldering alloys and fluxes are rapidly selected according to the base metal to be joined. *All-State Welding Alloys Co.*

1728. Brazing Copper
Bulletin 20 from *Handy and Harman* discusses "Sil-Fos 5," a silver brazing alloy for joining copper alloy components.

Circle appropriate number on Reply Card, p. 48-B



1729. Electron Beam Welding
To learn more about electron beam welding, send for pamphlet issued by *Sciaky Bros., Inc.* Low voltage and redesigned chamber eliminates x-ray hazards.

1730. A-C Welders
Miller Electric Mfg. Co. will send you complete details on a 300 or 500 amp. "Model S" heavy-duty a-c. welder which features movable coil design and 80 volts open circuit for fast arc starting.

1731. Induction Brazing
The *Ohio Crankshaft Co.* has pamphlet entitled "Typical Results of Tocco Induction Brazing and Soldering."

1732. Welding Electrodes
Harnischfeger announces the availability of Leaflet R-29 on "P&H 170LA" all-position electrodes (E7018).

1733. Silver Brazing
American Platinum & Silver Div. has literature on "Silvaloy" low-temperature brazing alloys and fluxes for your specific brazing requirements. *Englehard Industries, Inc.*

Testing

1734. "Edgegraphing"
16-p. data sheet explains Edgegraphing, a new technique for hand analysis of complex engineering data in 10, 20, or more variables. *Statistical Engineering Institute.*

1735. Hardness Testing
Reference book containing complete information on hardness testing. Easy-to-read text with many illustrations. *Clark Instrument, Inc.*

1736. Testing of Metals
Ten-page Bulletin M-2 from *Instron Engineering Corp.* covers all fields of precision metals testing.

1737. Research Metallographs
Catalog E-240 shows how industry can boost output and maintain quality by providing detailed magnified images for routine work and advanced research. *Bausch & Lomb Inc.*

1738. Information Searching
Brochure discusses Documentation Service which delivers the world's current metallurgical literature to you every two weeks in digest form. *American Society for Metals.*

1739. Potentiometer Controls
Minneapolis - Honeywell's "Electronic 15" potentiometers have modules with operating features that provide automatic d-c. voltage sources. Batteries, standard cells, and standardization mechanisms are not required.

1740. Surface Finish Measurements
Two illustrated folders explaining "Nomarski" polarization interferometer and the "Interference Contrast" technique will be sent to you by *William J. Hacker & Co., Inc.*

1741. Laboratory Microscopes
Catalog 2-M discusses line of metallographs, including an inverted metallurgical microscope which contains many features usually found only in larger metallographs. *Unitron Instrument Co.*

1742. Testing Machines
Detroit Testing Machine Co. has issued folder on standard and custom testing machines for determining hardness, ductility, compression, and tensile strength.

1743. Proving Rings
Steel City Testing Machines will send literature detailing the advantages of proving rings to measure compression or tension loads; capacities to 200,000 lb.

1744. Metallurgical Microscopes
The M12 metallurgical microscope offers superior optical performance and versatility of application. Details available from *Cooke, Troughton & Simms, Inc.*

1745. Metals Handbook
32-p. brochure illustrates contents of new Metals Handbook, 8th Edition, Vol. 1, "Properties and Selection of Metals." *American Society for Metals.*

1746. Metallograph and Camera
American Optical Co. will send complete information on the "Workhorse" metallograph which combined with the Polaroid Land Camera gives you photographic prints in 60 sec.

1747. Thickness Gage
The *Ohmart Corp.* has issued Specification Sheet BG detailing methods of operations and outlining features of a nuclear thickness gage employing beta radiation.

1748. Gas Analyzer
Consolidated Electrodynamics has published a pamphlet on a "Type 21-611" mass spectrometer, a low-cost easy-to-operate gas analyzer for batch or continuous analyses.

1749. "The Laboratory"
32-p. journal features new developments in instruments, apparatus, lab furniture, reagent chemicals, and methodology. *Fisher Scientific Co.*

1750. Hardness Testing
By controlling the hardness of incoming parts you can reduce processing steps and minimize broken tools. Literature available from *Steel City Testing Machines.*

1751. Sulfur Determinator
16-p. bulletin from *Harry W. Dietert Co.* discusses three-minute analysis with a "Dietert-Detroit" sulfur determinator.

1752. X-ray Film
Pamphlet from *Ansco Div.* gives the facts on "Superay A and B Monopak" x-ray films for improving your inspection efficiency.

1753. Tension Testing
Information is available from *Wiedemann Machine Co.* on the "Wiedemann-Baldwin Mark E" tension testing machine with a maximum capacity of 10,000 lb.

1754. Tukon Tester
The accurate way to test microhardness is with a Tukon hardness tester. Catalog RT-58 from *Wilson Mechanical Instrument Div.*

1755. Electrolytic Polisher
Leaflet from *Buehler Ltd.* describes "No. 1720 AB" polishers, designed for trouble-free service and ease of operation in electropolishing metallurgical samples.

1756. Torsion Testing
Bulletin 58 gives the full story on *Tinius Olsen* torsion testing machines. Six models in capacities from 60,000 to 1,000,000 in-lb.

1757. Spectrographic Analysis
Brochure from *Jarrell Ash* describes compact "Atomcounter," a direct-reading polychromator which can analyze a sample for as many as 22 elements in less than two minutes.

1758. Electron Microscope
Radio Corp. of America will send information on their electron microscope which has an automatic vacuum system for a high output of micrographs.

1759. Universal Tester
Bulletin RU-2-60 describes a universal testing machine which combines ruggedness and sustained accuracy with trouble-free service. *Riehle Testing Machines Div.*

NEW 15-MINUTE X-RAY OF AN ALLOY MEANS STILL HIGHER QUALITY... STILL FASTER SERVICE FROM C-M.

HERE'S THE RESULT OF A GREAT NEW ADVANCE IN QUALITY CONTROL — A COMPLETE ALLOY ANALYSIS ON PRINTED TAPE OBTAINED WITH THE UNIQUE NEW X-RAY SPECTROGRAPHIC PROCESS. THIS NEW METHOD BENEFITS YOU TWO IMPORTANT WAYS: FIRST, IT MAKES ALLOY ANALYSIS MORE ACCURATE THAN EVER BEFORE . . . WHICH MEANS ADDED CERTAINTY THAT YOUR ALLOYS ADHERE RIGIDLY TO QUALITY SPECIFICATIONS. ALSO, THIS NEW X-RAY PROCESS MAKES THE COMPLETE ANALYSIS IN JUST 15 MINUTES INSTEAD OF 3 DAYS. TOTAL RESULT: STILL HIGHER QUALITY, BETTER SERVICE, FASTER DELIVERY. A POST CARD BRINGS FULL INFORMATION.

ULTRA MET VACUUM ALLOYS

CANNON-MUSKEGON CORPORATION

METALLURGICAL SPECIALISTS • 2879 LINCOLN AVENUE • MUSKEGON, MICHIGAN

PRODUCERS OF IRON, NICKEL AND COBALT ALLOYS: SHEET, WIRE, BAR, FORGINGS, INGOTS, SHOT

Circle 1868 on Page 48-B

1760. Research Microscope
16-p. catalog explains the "Reichert" polarizing research microscope "Zetopan-Pol" used for research applications. *William J. Hacker & Co.*

1761. Metallographic Equipment
Get all the facts on the important features and conveniences built into "Model MM5 Micro-Metallograph." *E. Leitz, Inc.*

1762. Process Controllers
56-p. Catalog C15-2a covers complete line of "Electronik" controllers, both pneumatic and electric. *Minneapolis-Honeywell.*

1763. Industrial X-ray Film
Brochure from *Eastman Kodak Co.* details the advantages of industrial x-ray film, Type AA and Type M in 16, 35 and 70mm. widths, and up to 200 ft. lengths.

Casting

1764. Shell-Molded Castings
Bulletin G-159 from *Duraloy Co.* describes shell-molded castings which permit more intricate design and thinner wall sections.

1765. Power-Spinning Mandrels
"Meehanite" hydrospinning mandrels, heat treated to Rockwell C-50, offer many design, economic and production advantages. Brochure from *Meehanite Metal Corp.*

1766. "Refractories"
Featured in Vol. 5, No. 1, is the article "Effects of Radiation and Convection on Heat Flow." *Carborundum Co.*

1767. Magnesite-Chrome Brick
H. K. Porter Co., Inc. announces the availability of literature on "Kilmag Cladex," a burned magnesite-chrome brick for use in rotary kiln hot zones.

1768. Induction Melting System
Bulletin 20-15 describes the M-G powered "Inducto Integral 15" a melting unit which reduces maintenance and operating costs appreciably. *Indoctotherm Corp.*

1769. Fluorspar Briquets
Leaflet from *Glen-Gery Shale Brick Corp.* tells about "Glen-Spar," high-purity fluorspar in briquet form for improved melting and fluxing operations.

1770. Gas Analyzer
Booklet sets forth the details on a *Perkin-Elmer* furnace atmosphere analyzer which automatically records volume percent of each of the four gases: O_2, CO, CO_2, and CH_4.

1771. Vacuum Furnaces
24-p. Bulletin 4-25 from *Consolidated Vacuum Corp.* discusses vacuum metallurgy, vacuum arc-melting furnaces and vacuum induction-melting furnaces.

1772. Mechanical Booster Pump
Kinney Vacuum Div. has published Pamphlet 3180.1 on the "Model KMB-30," a mechanical booster high-vacuum pump which provides high pumping speed and low ultimate pressure (0.0005 microns).

1773. Columbium Additions
Information available from *Molybdenum Corp. of America* on columbium additions to steel, which provide greater strength with less weight, good formability and good weldability in the finished product.

1774. Vacuum-Melted Steels
Complete details on "Midvac" steels plus comparative analysis of leading superalloys are available in brochure from *Midvale-Heppenstall Co.*

1788. Refractory Cement
Universal Atlas Cement Div. has published a leaflet recounting the advantages of "Lumnite" cement for refractory applications such as slow-cooling pits.

1789. Fluid Mixing
Mixing Equipment Co. will send Bulletin B-521 on "Lightnin Mixers"; capacities from 1/4 to 3 hp.

1790. Oxygen Plant
Oxygen for steel manufacturing is always on tap when it is piped from an Airco plant. Get the full story from *Air Reduction Sales Co.*

1791. Vacuum Equipment
Find out why you get more pumping performance per dollar with "Microvac" pumps. *F. J. Stokes Corp.*

1792. Block Insulation
At temperatures to 1900° F., "Superex" block insulation provides greater efficiency and longer operating life. Details from *Johns-Manville Co.*

1793. Industrial Blowers
Catalog No. 126B contains specifications on blowers in standard capacities of 1/3 to 1000 hp., up to 20,000 cfm., and 4 oz. to 10 lb. pressure. *Spencer Turbine Co.*

1794. Ramming Mix
Folder from *Kaiser Refractories & Chemicals Div.* covers application of "Permanente 165," a high-magnesia ramming mix for use in openhearth steel furnaces.

Parts

1795. Aerospace Bolts
24-p. selection guide to bolts for aerospace industries is offered by *Standard Press Steel Co.* Tension and shear bolts, engine bolting, titanium and specialty fasteners made to AN, MS and NAS standards.

1796. Wire Baskets
8-p. Bulletin B-10 covers woven wire baskets for degreasing, dipping, heat treating, plating, pickling, ultrasonic or chemical cleaning applications. *Newark Wire Cloth Co.*

1797. Electrical Contact Rivets
Bulletin No. 400 describes "Atomiclad" electric contact rivets which bond a noble metal contact surface to a rivet body, providing superior physical and electrical properties at lower cost. *Gibson Electric Sales Corp.*

1798. Socket Screws
The *Holo-Krome Screw Corp.* has issued Data Sheet JS-1961 on socket jam screws which feature clear-through hexagon sockets.

1799. Metal Shapes
Catalog 760 recounts the advantages of roll-formed metal shapes in producing better products at lower cost. *Roll Formed Products Co.*

1800. Metal-Mesh Belts
The *Cambridge Wire Cloth Co.* has published a 130-p. reference manual containing information on a complete line of metal-mesh belts in special and standard alloys to meet your specific requirements.

1801. Industrial Fasteners
8-p. bulletin offered by *Standard Pressed Steel Co.* describes complete line of standard precision industrial fasteners including socket screw products, locknuts, and dowel pins.

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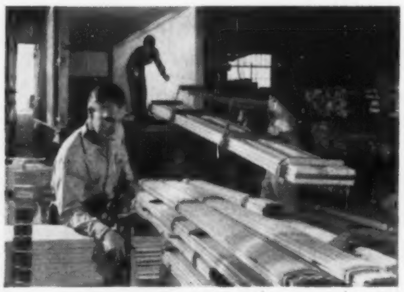

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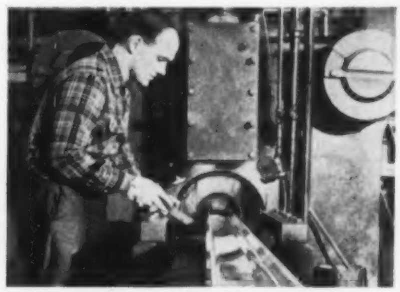

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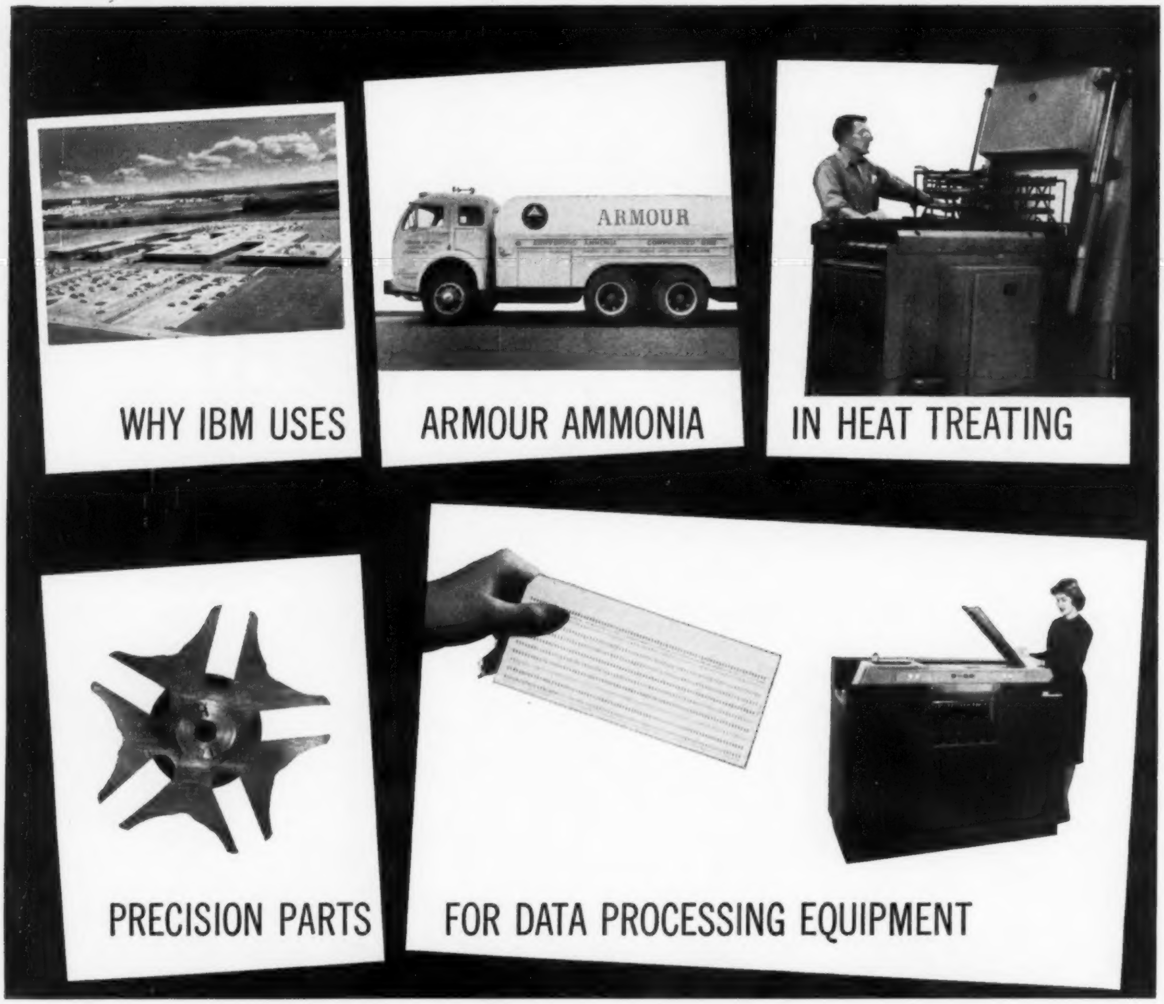

Precise heat treating results are a must for vital components of the electronic marvels produced by International Business Machines Corp. in Rochester, Minnesota.

IBM heat treats about four million parts a year in Armour ammonia atmospheres. Heat treating processes used include carbonitriding, nitriding, annealing and brazing. A good example of one of these parts is the Geneva Star Wheel shown above, which must be precise and as wear-resistant as possible.

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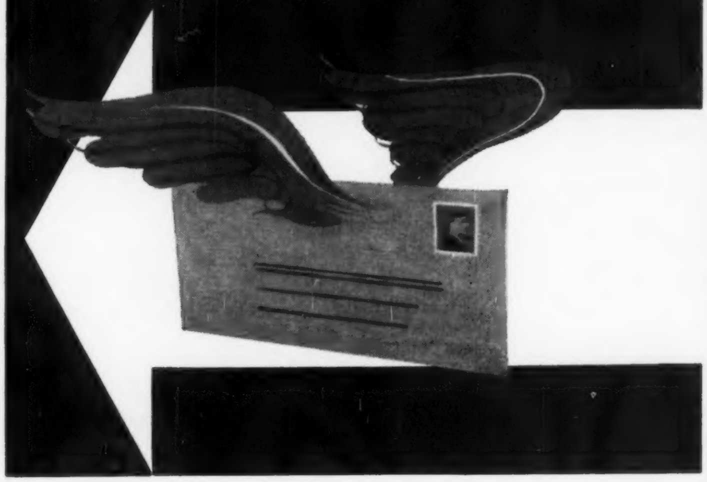

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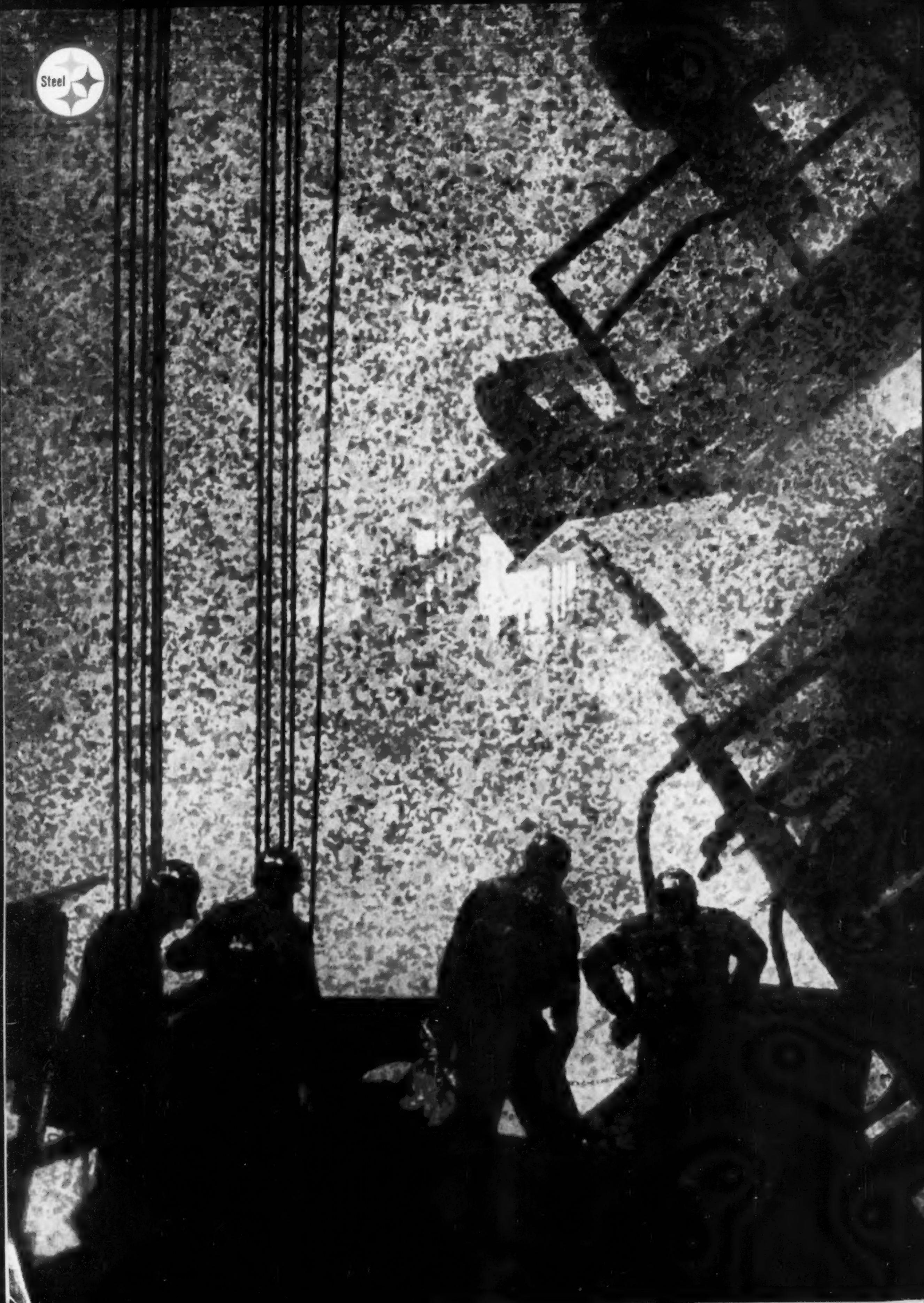
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"PARK HEAT TREATING SALTS help us harden tools properly"

SAYS O. J. WILLIAMS SR., PRESIDENT OF METAL TREATING INC., CINCINNATI, OHIO.

Left to right: O. J. Williams Sr., President; O. J. Williams Jr., Chief Metallurgist; George Theurer, General Manager & Treasurer; James F. Hetz, Park Sales Representative.

"Our customers appreciate the high quality of our work and we appreciate the high quality of Park heat treating salts. They furnish rapid, uniform heating without distortion and with no decarburization, pitting or scaling. Our production and quality have increased considerably since we started using Park salt baths. We have come to know them as indispensable assets to our tool hardening operations." Molten salt baths are now generally accepted as the ideal mediums for heat treating tool steels. A majority of the country's leading tool makers and commercial steel treaters use Park salt baths. Tool makers and users are concerned with fine quality and low cost heat treating. Park's heat treating materials and technical service, together with improved salt bath furnace construction, are largely responsible for the vast improvement in the hardening of tools. Park Chemical Company manufactures a complete line of heat treating materials and are happy to help you with your heat treating problems. No obligation, of course. Call or write today.

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SCIAKY ELECTRON BEAM WELDING

Here's how you can combine precision research and practical production electron beam welding in one equipment installation

Whether your interest in electron beam welding processes is for highly precise research or practical production work—or both—your data should be complete with details on Sciaky machines. They are most simple and practical in concept and operation.

GUN DESIGN GIVES EXCEPTIONAL ELECTRON OPTICS

The Sciaky Electron Gun produces specific beam density previously possible only with accelerating potential higher than 100,000 volts. The Sciaky gun, entirely contained within the atmosphere of the welding chamber, will operate in any angular position. *Both* gun and fixture can be moved to any position within the chamber while welding.

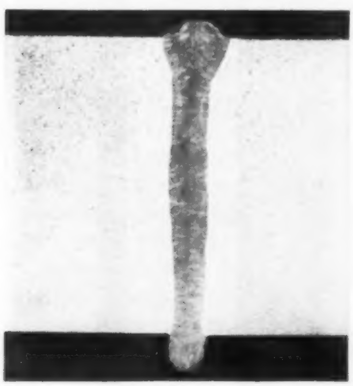

Figure 1

Advanced focusing design results in electron beam welds of 12 to 1 depth to width characteristics. Figure 1 shows a deep penetrating butt weld in type 304 stainless steel. Plate thickness is .5". Note lack of heat-affected zone.

GUN AN INDUSTRIAL TOOL

The gun construction is simple and rugged. Precise alignment is inherent in design, and is not dependent upon assembly adjustments. If necessary, filaments can be easily and quickly replaced in less than five minutes. As shown in Figure 2, the Sciaky Electron Beam Gun is small and

Figure 2

compact. A simple spacer arrangement optimizes gun optical system throughout a wide range of output power without compromise of specific beam energy. As a result, the

Figure 3

Sciaky gun is optimized at current ranges of 250, 150, 100 and 50 MA. at 30,000 volts. Output power is continuously adjustable within each range.

EFFICIENT PUMPING SYSTEM

Evacuation of chamber to welding pressure is obtained within 3 to 10 minutes, depending on chamber size. Pumping sequence is fully automatic, and without any manual adjustment. Automatic safety devices insure trouble-free operation and full protection of system.

RADIOLOGICAL HAZARDS ELIMINATED

Low voltage (30,000 v. maximum) and highly refined chamber design eliminate x-ray hazards to operator, which are a severe problem with higher voltage equipment. As a result, the Sciaky low voltage system needs no costly shielding, even when welding at highest output.

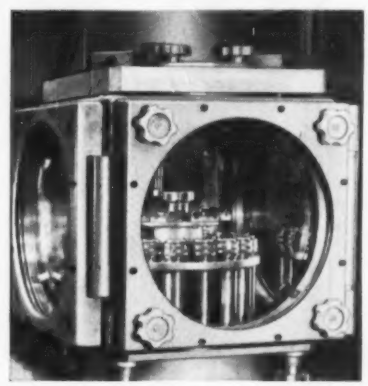

Figure 4

As shown in Figures 3 and 4, complete accessibility and visibility are provided by this latest Sciaky design. All sequence controls of the dial feed unit (Figure 4) are fully automatic. This production unit is being used to weld end-caps to tubes.

Regardless of your specific area of interest, you'll find the Sciaky combination of welding experience and electron beam technology is well advanced. Sciaky is Exclusive Licensee under Stohr, U.S. Patent 2,932,720.

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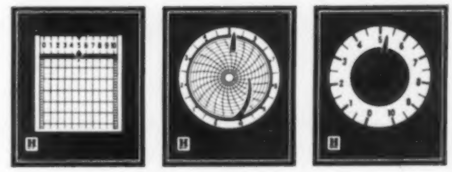

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In addition, modular construction makes *ElectroniK 17* instruments easiest of all potentiometers to operate, convert and maintain. Complete interchangeability of components cuts service downtime and minimizes spare parts stocking requirements for these advanced potentiometers.

You can get *ElectroniK 17* instruments as strip or circular chart recorders or circular scale indicators. You can get electric contact control with up to 8 contacts. All control units are of convenient plug-in type.

ElectroniK 17 is one of the great advances in potentiometry, and you should have all the eye-opening facts about this new class of instruments. For complete details, call your nearby Honeywell field engineer, or write MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa.—In Canada, Honeywell Controls, Ltd., Toronto 17, Ontario.

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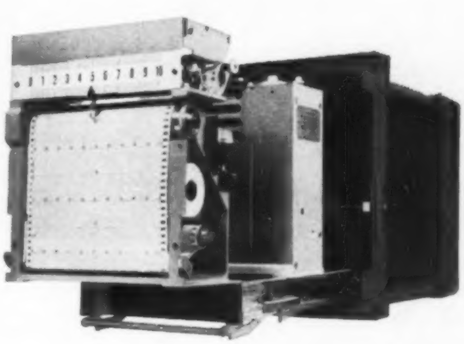
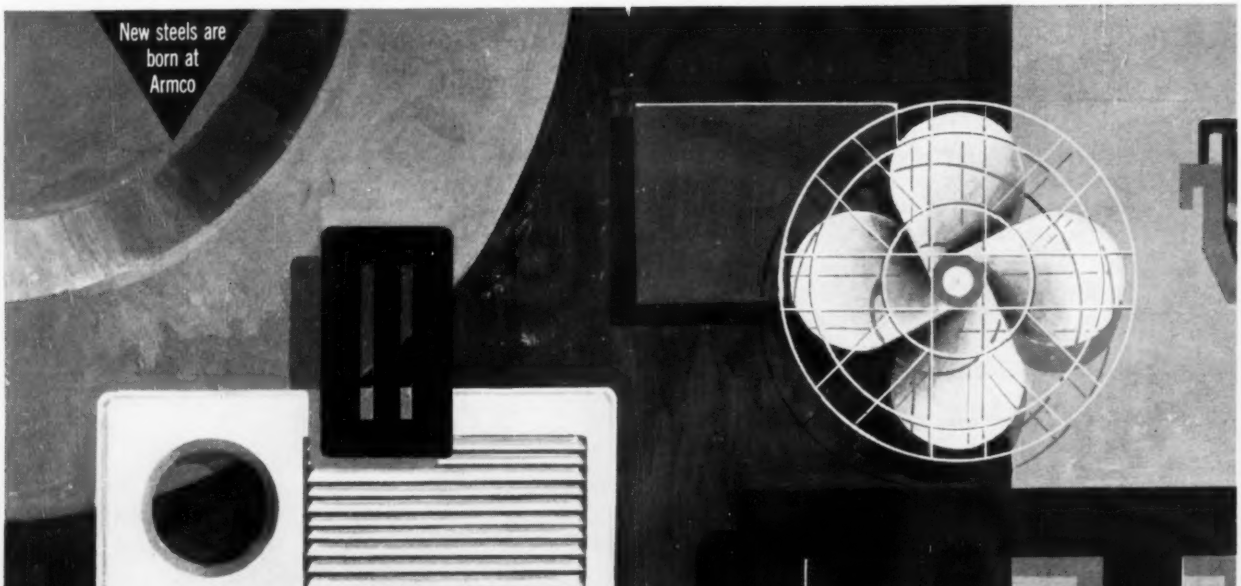
True modular construction saves you time, trouble, money. Three basic modules—case, display and drive—make up the *ElectroniK 17*. The case fits standard 19-inch relay racks. You can remove the door easily and without tools when converting from strip chart to circular chart or circular scale operation. You can pull out the chassis to the service position without tools, and without interrupting operation, or remove it completely. You can change chart speeds to ½ or 2 times basic speed (Standard chart speeds: 1, 2, 6, 10, or 60 inches per hour) by replacing quick-change drive gears. You change range and actuation simply by changing cards. Zener diode constant current supply eliminates battery problems. Up to 8 plug-in contact control modules provide for a wide variety of control possibilities.



HONEYWELL INTERNATIONAL Sales and Service offices in all principal cities of the world. Manufacturing in United States, United Kingdom, Canada, Netherlands, Germany, France, Japan.

Circle 1806 on Page 48-B

Now, Two Armco Enameling Metals Expand Design Potential of Porcelain Enamel



Porcelain Enameled Steel

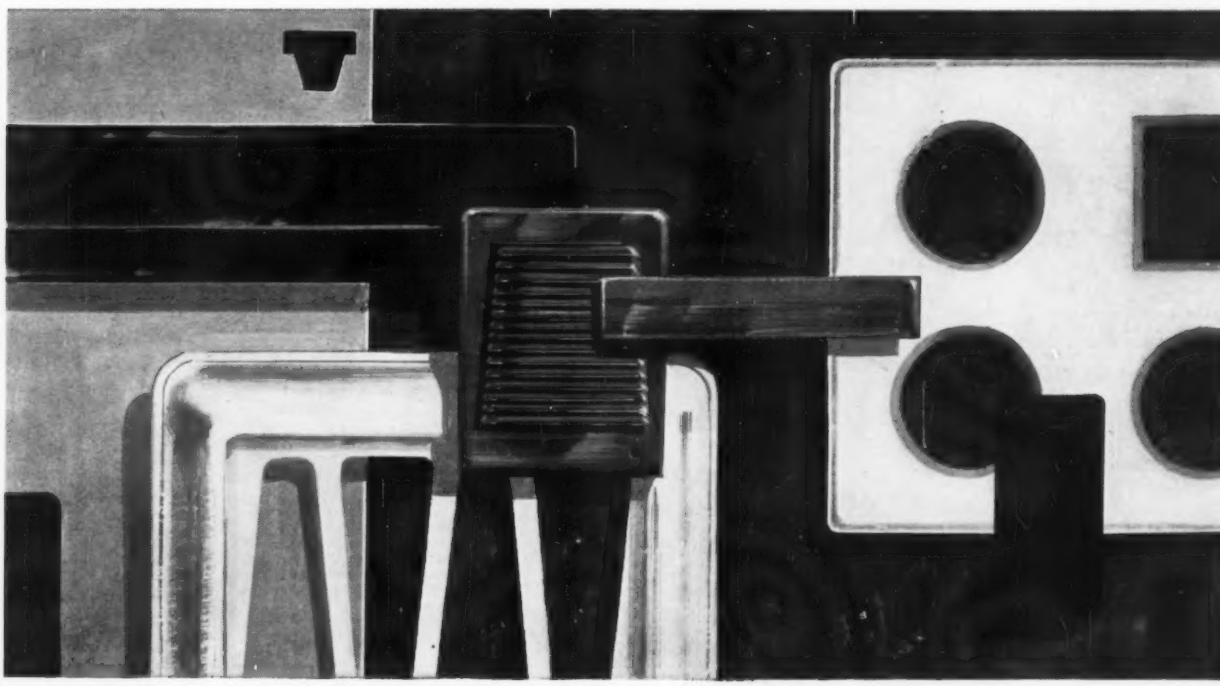
For color, form, durability

"Direct-on" porcelain enameling with new Armco UNIVIT® assures real production economy. This special metal opens an entirely new field for designers of many kinds of products.

UNIVIT permits one-coat, one-fire porcelain enameling without danger of boiling or fishscaling. The smooth, attractive finish fights abrasion and corrosion, provides exceptional resistance to mechanical damage and thermal shock. Best of all, *cost of porcelain enamel on UNIVIT compares favorably with baked enamel or vinyl finishes.*

For high-quality two-coat porcelain enameling, Armco produces Armco Enameling Iron, long known as "The World's Standard." It is noted for its excellent enameling properties, workability, and freedom from sag in firing.

Behind both UNIVIT and Armco Enameling Iron is Armco's unmatched production record and service experience developed through more than 50 years as the world's foremost supplier of base metal for high-quality porcelain enameling. Together, they offer wide latitude for designers seeking to give products the color, form and durability of porcelain enamel. Call your Armco sales office or write Armco Division, Armco Steel Corporation, 1811 Curtis St., Middletown, Ohio.



ARMCO **Armco Division**

Wherever aluminum needs heat

LINDBERG FISHER

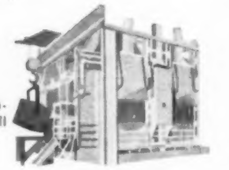
You'll find this nameplate on all the equipment you'll need for applying heat to aluminum. Heat and aluminum have been Lindberg's babies for years. Our staff of expert engineers, metallurgists and technicians is widely experienced in all phases of aluminum melting, casting, and treating and has pioneered many important developments in aluminum processing by heat. Today, Lindberg offers you a complete line of heating equipment for every requirement in this field. This includes every needed type of melting, holding or heat treating furnace, large and small, shop built or field erected, fuel fired or electric (resistance, 60 cycle induction, arc or high frequency). We hope you'll let our symbolic friend, "Little Joe", guide you through the exposition of this equipment offered on these pages.

Meet "Little Joe"! He looks something like a fellow in our plant but we really use him as a symbol of the good right hand of service Lindberg-Fisher's expert design staff and our complete line of "heat for aluminum" equipment is able to render you.

Hot Metal Delivery

MELTING

"RIGHT FROM THE START, LINDBERG EQUIPMENT TAKES OVER YOUR ALUMINUM HEATING NEEDS."

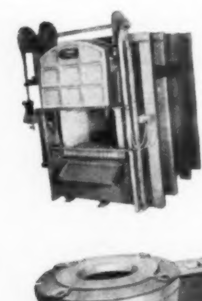


Fuel fired reverberatory. Charging well optional.

"MOLTEN METAL FROM REDUCTION CELLS IS HELD, OR INGOTS MELTED, IN FURNACES LIKE THESE."

CASTING STATION

"MOLTEN METAL IS HELD AT THE CORRECT TEMPERATURE UNTIL PROCESSED INTO CASTINGS."

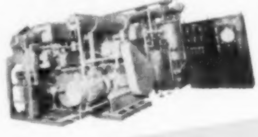


Fuel fired reverberatory, holding or melting.

Fuel fired crucible or pot, holding or melting, stationary. **New radiant wall type also available.**

"MANY CASTING STATION FURNACES CAN BE EQUIPPED WITH THE LINDBERG AUTOLADLE, NAMED 'LITTLE JOE', AFTER ME."

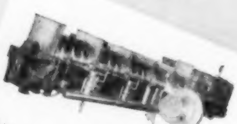
Autoladle for automatic ladling, four shot sizes available, up to 100 lbs.



HYNI nitrogen generator, for atmosphere melting and fluxing.

SPECIAL EQUIPMENT

"SOME CASTINGS MAY REQUIRE HEAT TREATMENT AND THESE ARE HANDLED IN THE FURNACES BELOW."



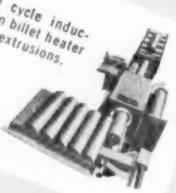
Gas fired billet heater for extrusions.

"SO, DOWN TO THE FINISHED PRODUCT, LINDBERG EQUIPMENT TAKES CARE OF EVERY STEP."

HEAT

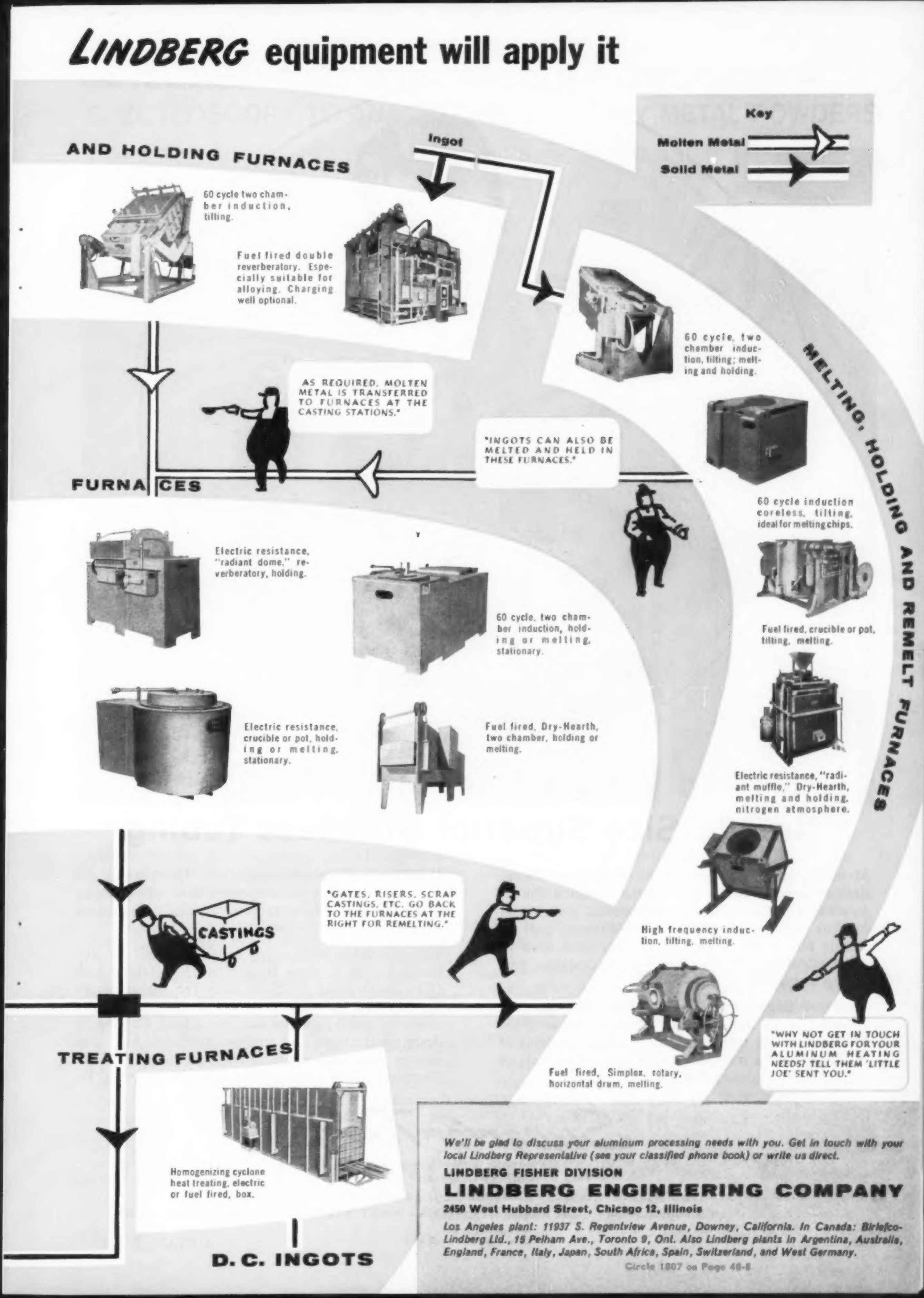
Cyclone heat treating, electric or fuel fired, box or pit.

Cyclone heat treating, electric or fuel fired, box or pit.



60 cycle induction billet heater for extrusions.

BILLETS **RODS** **CASTINGS**


LINDBERG equipment will apply it
Key
Molten Metal
Solid Metal
Ingot
AND HOLDING FURNACES
60 cycle two chamber induction, tilting.
Fuel fired double reverberatory. Especially suitable for alloying. Charging well optional.
60 cycle, two chamber induction, tilting; melting and holding.
MELTING, HOLDING AND REMELT FURNACES
"AS REQUIRED, MOLTEN METAL IS TRANSFERRED TO FURNACES AT THE CASTING STATIONS."
"INGOTS CAN ALSO BE MELTED AND HELD IN THESE FURNACES."
FURNACES
60 cycle induction coreless, tilting, ideal for melting chips.
Electric resistance, "radiant dome," reverberatory, holding.
60 cycle, two chamber induction, holding or melting, stationary.
Fuel fired, crucible or pot, tilting, melting.
Electric resistance, crucible or pot, holding or melting, stationary.
Fuel fired, Dry-Hearth, two chamber, holding or melting.
Electric resistance, "radiant muffle," Dry-Hearth, melting and holding, nitrogen atmosphere.
"GATES, RISERS, SCRAP CASTINGS, ETC. GO BACK TO THE FURNACES AT THE RIGHT FOR REMELTING."
CASTINGS
High frequency induction, tilting, melting.
TREATING FURNACES
Fuel fired, Simplex, rotary, horizontal drum, melting.
"WHY NOT GET IN TOUCH WITH LINDBERG FOR YOUR ALUMINUM HEATING NEEDS? TELL THEM 'LITTLE JOE' SENT YOU."
Homogenizing cyclone heat treating, electric or fuel fired, box.
D. C. INGOTS
We'll be glad to discuss your aluminum processing needs with you. Get in touch with your local Lindberg Representative (see your classified phone book) or write us direct.
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Los Angeles plant: 11937 S. Regentview Avenue, Downey, California. In Canada: Birlefco-Lindberg Ltd., 15 Pelham Ave., Toronto 9, Ont. Also Lindberg plants in Argentina, Australia, England, France, Italy, Japan, South Africa, Spain, Switzerland, and West Germany.
Circle 1807 on Page 48-B

Wind Velocities to Mach 7 Prove Needle-Size Superior Stainless Tubing

Manometer lines of Superior Type 304 stainless tubing, drawn to needle size, withstand the vibration caused by air speeds beyond Mach 7 and internal pressures as high as 5000 psi in FluiDyne wind-tunnel tests of missile component models. And they have been in some assemblies for 3½ years without cracking, pinholing or buckling.

FluiDyne Engineering Corp., one of the major designers of such test facilities, attributes the long life of this Superior tubing to both its high modulus of elasticity and its resistance to the corrosive effects of mercury and soldering-flux acid.

Ductility is a big advantage, too. This permits the Superior tubing to be easily hand-bent into complex shapes for application in wind tunnels and readout equipment.

Filling stainless steel tubing orders that call for tiny needle tubing in gages from 6 to 33 or tubing with OD's as large as 1.125 in. calls for the resources Superior has to offer. Why not investigate us as a source of small-diameter stainless tubing. Catalog 21 describes the types and analyses available. Also gives tips on its selection and application. Superior Tube Company, 2008 Germantown Ave., Norristown, Pa.

Superior Tube

The big name in small tubing

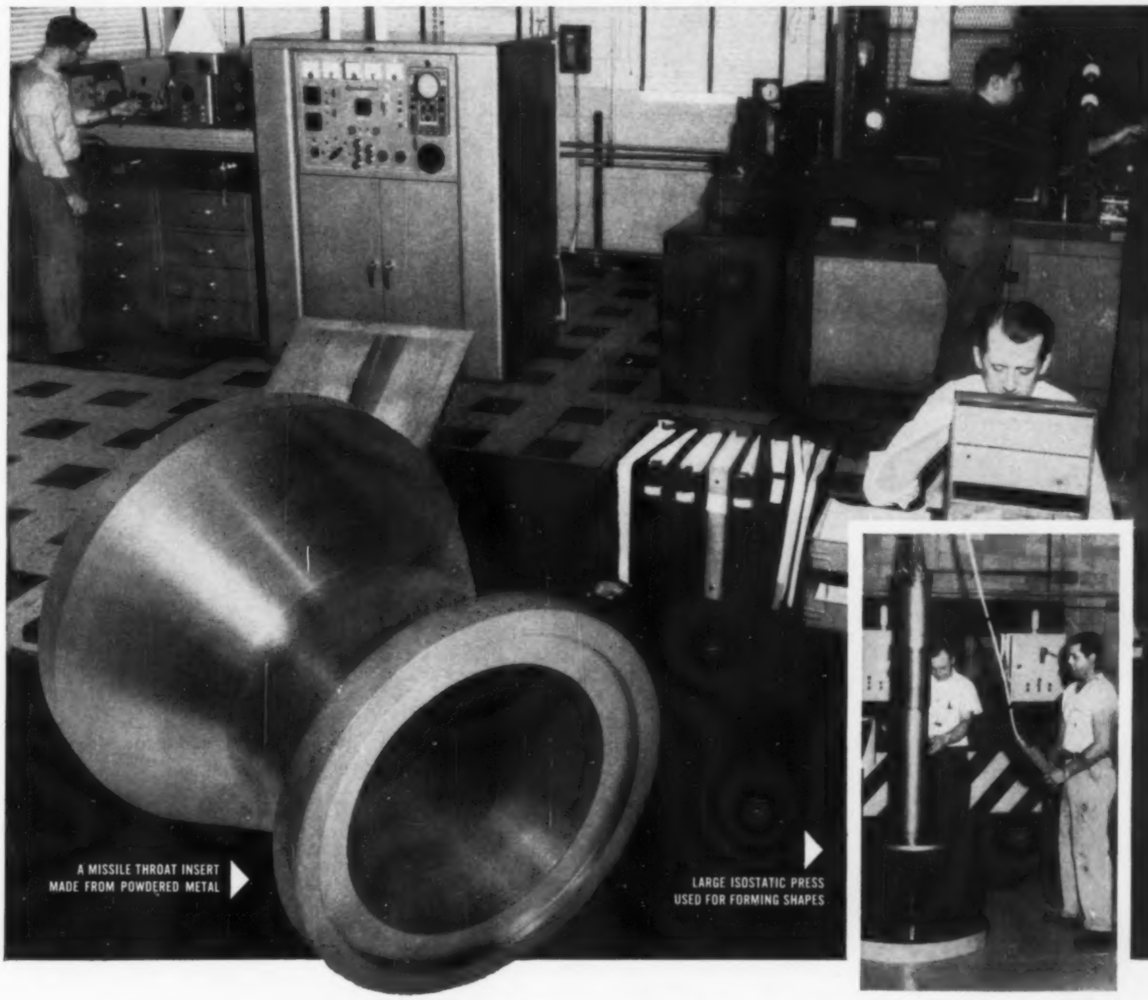
NORRISTOWN, PA.

All analyses .010 in. to ⅝ in. OD—certain analyses in light walls up to 2½ in. OD

West Coast: Pacific Tube Company, Los Angeles, California • FIRST STEEL TUBE MILL IN THE WEST

Circle 1809 on Page 48-B

SYLVANIA ELECTRIC PRODUCTS INC. USES EMISSION SPECTROSCOPY TO ANALYZE REFRACTORY METAL POWDERS



Spectroscopy is an important tool in the production of molybdenum and tungsten metal powders at Towanda, Pennsylvania by the Chemical and Metallurgical Division of Sylvania Electric Products Inc., a subsidiary of General Telephone and Electronics Corporation.

In the modern spectrographic laboratory above, numerous direct-method in-process material checks are made. Finally, critical trace elements in the range of 0.1 to 50 PPM are identified in the refractory metal powders.

Results — obtained quickly and accurately by emission spectroscopy — permit this firm to control the purity of molybdenum and tungsten powder which means more efficient processing to a high-quality end product.

"National" Graphite grade SPK preformed electrodes play an important part in these determinations. Highest purity combined with improved uniformity and reproducibility make grade SPK an outstanding spectrographic electrode.

The superior structure and strength of SPK electrodes have practically eliminated breakage of the thin crater walls of sample-bearing electrodes.

Write today for new spectrographic electrode catalog. Address: National Carbon Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y. In Canada: Union Carbide Canada Limited, Toronto.

NATIONAL CARBON COMPANY

UNION CARBIDE

Circle 1810 on Page 48-B

• MACHINES UP TO 50% FASTER
• LENGTHENS TOOL LIFE

Uniloy 303MA is a free machining grade of chromium-nickel stainless steel developed by Universal-Cyclops. It has been proven greatly superior to AISI Type 303 in key plants throughout the country.

Production tests have proved that Uniloy 303MA machines up to 50% faster than Type 303. Cutting tools last longer, decreasing tool cost and machine down time. Completed parts have a better finish than is possible with Type 303, and the corrosion resistance is far superior.

Send for a copy of our new brochure containing complete data on Uniloy 303MA, and for Performance Reports citing dollar savings achieved by satisfied customers.

Contact your nearest Universal-Cyclops steel service center or sales office. Uniloy 303MA is AVAILABLE FOR IMMEDIATE DELIVERY.

*Patent No. 2,900,250

UNIVERSAL CYCLOPS
STEEL CORPORATION
EXECUTIVE OFFICES: BRIDGEVILLE, PA.

STAINLESS STEELS • TOOL STEELS • HIGH TEMPERATURE METALS

Circle 1812 on Page 48-B

ONE KEY TO COST CONTROL IN '61

Savings like these through Metalogics*

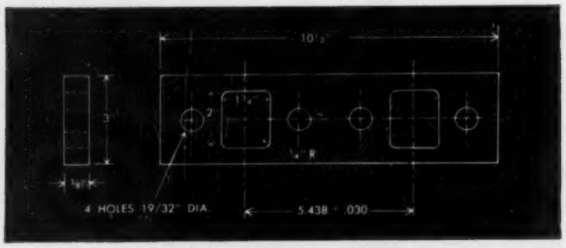
Look at these random examples and see how Ryerson Metalogics sparks real savings for hundreds of companies—in helping to search out new materials, new methods, new machines that will do the job better.

You can count on Ryerson for practical, unbiased recommendations because we offer you:

1. Exceptional knowledge of metals and their characteristics, gained through a century of service to industry as a supplier of metals and machinery for metal fabrication.
2. The nation's largest stocks of steel and aluminum —plus unsurpassed service on industrial plastics.

Your Ryerson representative is "Metalogics-trained" to help you value-analyze selection, fabrication and application problems. Get his constructive ideas soon, and see how he can help you select and apply material from our vast stocks. It's the "Metalogical" thing to do.

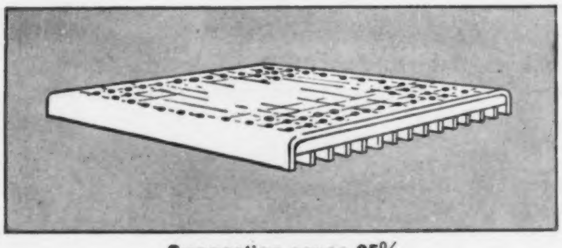
**The Ryerson science of giving optimum value for every purchasing dollar.*



Saved: $100 per thousand

PROBLEM: Muffler manufacturer required accurately finished mounting plates made from ¾" x 3" bar. Cutting bars to size, burning 1¾" x 2" holes and drilling four 19/32" holes proved time-consuming and expensive.

SOLUTION: Ryerson recommended that they eliminate cutting, burning and drilling operations by stamping the part from Ryerson forming-quality plate. One operation instead of three cut costs $100 per thousand pieces and quickly justified the small initial investment in dies.



Suggestion saves 85%

ASKED FOR: Customer wanted 1" hot rolled plate to cover about 80' of 24" open trench. Plate was to be cut into 24" x 27" segments—each containing 900 ⅜" holes to filter the product.

RECOMMENDED: After studying application and costs, Ryerson recommended a design combining perforated light plate, formed to channel shape, and grating for structural support. Ryerson's experience and imagination saved 85% of the original cost.

Machine cut rings solve problem

PLATES REQUESTED: Ryerson was asked to bid on supplying ¼" Type 410 stainless in 27½" square plates. Material was to be used for orifice plates for 16" burner, subjected to elevated temperatures.

RINGS RECOMMENDED: Going beyond material specs, the Ryerson representative found that the customer intended to cut plate into 27¼" diameter length with 13.120" bore—and then mill 12 slots in outer diameter for expansion relief. Knowing the application, Ryerson recommended supplying machine-cut rings in which slots could then be punched rather than milled. Production savings enabled switching to Type 304 at less cost than Type 410 with slots milled.

2 metalworking machines for the price of 1

A fabricator of stainless steel kitchen equipment was recently in the market for a new squaring shear. The one under consideration had a gap-type frame which would enable him to do an important notching operation—necessary for certain sink tops. After careful study, a Ryerson machinery specialist recommended *two* pieces of equipment instead of one at no increase in total cost. The first, an under-driven shear. The second, a universal-type sheet metalworking machine that would do the required notching, plus many other jobs—adding versatility to the entire operation.

Production upped 30%

BEFORE: Job shop was using MT 1015 tubing in the manufacture of this coupling. Machinability was satisfactory but rising costs of operation led to a search for ways to economize.

AFTER: Careful study by the Ryerson representative brought about a change in material. He recommended using Ledloy® 170 tubing, which increased machining speed to 170 sfm and stepped up production 30%. Ryerson's stocks include the widest range of fast-machining alloys.

STEEL • ALUMINUM • PLASTICS • MACHINERY

RYERSON STEEL®

Joseph T. Ryerson & Son Inc., Member of the INLAND Steel Family

Circle 1813 on Page 48-B

Ernest E. Thum
1884 - 1961

Ernest E. Thum

Sorrow shadows the American Society for Metals as we report the passing of Ernest Thum. Death came suddenly on April 10 while he was vacationing with his wife, Margaret, at Coronado Beach, Calif. For more than a quarter of a century he served the A.S.M. with distinction and dedication as editor of *Metal Progress* and in many other Society activities. The Society's highest award – honorary membership – was conferred on him in 1958.

Recognizing his many honors, which were deservedly awarded, we will remember him best for those qualities of mind and heart revealed in his everyday life. Unfettered by tradition, he had the uncanny ability to get right to the heart of a problem, whatever it might be. In minimum time he could ferret out the meat in an important technical article and report it in simple, understandable English. His unceasing mental activity, his untiring personal industry, and his indomitable will resulted in a trait of perseverance that carried his most cherished project – ***Metal Progress*** – to great technical success and world-wide recognition. He succeeded in giving his work a vitality and significance seldom achieved.

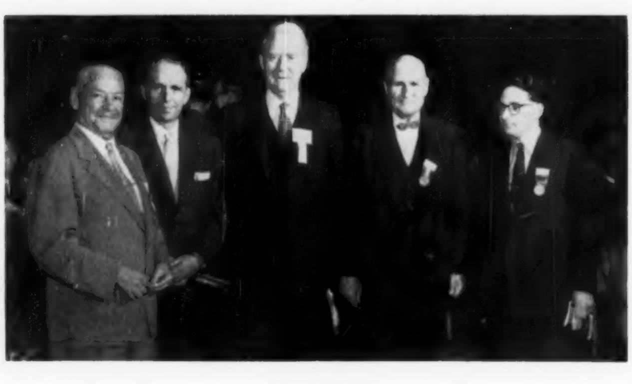
The American Society for Metals and the metals industry have benefited from the services of Ernest Thum. His advice and help in many areas of A.S.M. activities have been a large factor in the phenomenal growth of the Society. Early this year he was given added responsibilities as Director of Editorial Services which involved the coordination of work on all A.S.M. periodical and reference publications. In recent years, the editorial staff of *Metal Progress* has also grown as he envisioned . . . "this expanded editorial group will continue the development of *Metal Progress* in pace with the extraordinary tempo of modern technical and scientific advances and further enhance its prestige and unique position as the Magazine of Metals Engineering".

One of the greatest pleasures Ernest Thum had outside his work stemmed from his real love of music which found expression in a fine collection of records and staunch support of concerts in the community. Those who knew him felt his keen artistic sense would have made him successful in other fields had he not elected to follow a technical and engineering career. This artistic talent was reflected in the high standards of style and layout which distinguished *Metal Progress* from other technical magazines right from the start.

No truer measure of the worth and usefulness of any life can be found than the fruits of day-by-day achievement. The rearing of a fine family, the contribution of numerous ideas in his chosen field of work, the support of the cultural life of the community, and the widespread circle of acquaintances and friends who have been stimulated by his talent and warmth all add up to a far more eloquent tribute than words can convey. Ernest Thum will always live in the memories of those who have known and worked with him.

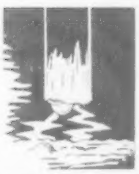
A Citation From the A.E.C.

A Meeting of the Metals Handbook Committee



At the World Metallurgical Congress

METAL PROGRESS
THE MAGAZINE OF MATERIALS AND PROCESS ENGINEERING
Vol. 79, No. 5 May 1961



Advances in Vacuum Technology

Consumable-Electrode Melting of Steels . . . Present and Future

*By W. W. DYRKACZ**

Since its adaptation to specialty steels and superalloys, consumable-electrode vacuum melting has proved to be a valuable technique for obtaining cleaner ingots which have lower gas content and better mechanical properties than comparable air-melted ingots. As a consequence, larger and larger remelting units are being built, and 60,000-lb. ingots will soon be available. (D5, D8m, D9)

Early in the last decade, American jet engine programs gave impetus to vacuum melting of superalloys. During the Korean War, engine builders began to use nickel-base alloys for turbine blades because cobalt had achieved strategic classification. Precipitation-hardening alloys had also been devised for turbine wheels. The most popular alloys to emerge during this period were M-252 and Waspalloy for blades, and A-286 for wheels. Because all of these alloys contained both high titanium plus aluminum, experience soon indicated that they could be more successfully produced with better quality and lower scrap rates by vacuum melting rather than by air melting.

The subsequent success of consumable-electrode remelting in providing alloys of high quality on a consistent production basis has led to increasing expansion of vacuum facilities in this country. In five years at our Watervliet

*Manager of Quality, Allegheny Ludlum Steel Corp., Watervliet, N.Y.

A Superalloy Ingot, 34 In. in Diameter and Weighing About 23,000 Lb., Is Transferred From Furnace Area at Watervliet Works of Allegheny Ludlum Steel Corp. Ingots up to 50 in. in diameter and weighing approximately 60,000 lb. can also be produced

Works alone, ingot sizes have increased in diameter from 16 to 40 in. This growth is continuing – we recently installed a furnace which will produce ingots up to 50 in. diameter and weighing upward of 60,000 lb.

Quality Is Higher

Vacuum melting has advantages over air melting in several major categories. Vacuum-melted alloys generally contain less gas and are cleaner and sounder than comparable air-melted alloys. Also, the method is suitable for several of the new metals and alloys which cannot be melted economically, or with any degree of predictability of yields and quality, by conventional methods.

To point up the differences between these two methods, let us discuss some of them further. First, vacuum-arc remelting reduces the gas content significantly compared to air melting. For example, hydrogen in air-melted steels can be as high as 15 ppm.; vacuum melting will reduce it to 1 to 2 ppm. consistently. Substantial reductions are also obtained in oxygen and nitrogen.

Since cleanliness is often a function of gas content, it is no surprise that consumable-electrode remelting improves cleanliness signifi-

cantly. Today, alloys are being produced on a production basis to cleanliness specifications far more stringent than those for air-melted material.

For example, with regard to bearing steels, there are several differences between micro-cleanliness specifications to which air-melted and vacuum-melted steels are purchased in America today. Specifications for air-melted material permit averages of field ratings. In contrast, cleanliness ratings on vacuum-melted material must be obtained from the worst field in any specimen. Furthermore, there is an additional limitation on the number of fields allowed with certain ratings in any specimen.

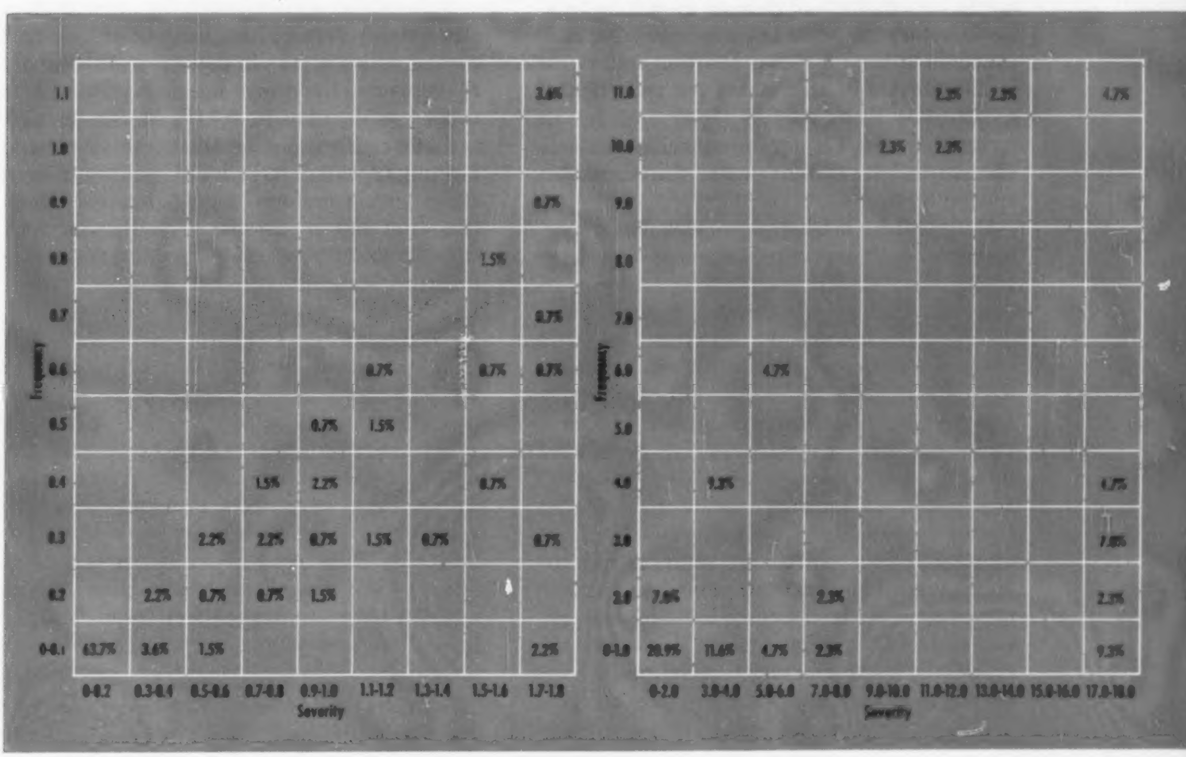
Regarding magnetic-particle inspection, specifications call for evaluating low-alloy and martensitic stainless steels by rating frequency and severity (F/S) of the magnetic-particle indications on the sample. Frequency is determined by counting the number of indications present, and severity is determined by assigning a weighted factor to each indication (with the factor increasing as the length of the indication increases). Then, the individual factors are totaled, and divided by the area (in square inch) of the sample.

Specifications for magnetic-particle inspection of air-melted and consumable-electrode vacuum-remelted steels are compared in the table below along with an explantion of how weighted factors are determined from the length of magnetic-particle indications.

	Frequency/Severity Rating
Air melted (standard)	10/20
Air melted (special)	5/10
Consumable electrode vacuum melted	0.5/1.0

Air Melted		Consumable Electrode Vacuum Melted	
Indication Length	Weighted Factor	Indication Length	Weighted Factor
⅛ to ¼ in.	1	1/64 to 1/32 in.	2
¼ to ½	2	1/32 to 1/16	4
½ to ¾	4	1/16 to ⅛	16
¾ to 1	8	⅛ in. and over	256
1 in. and over	16		

Fig. 1 – Frequency Distributions in Vacuum-Remelted Ladish D 6 AC (Left) and Air-Melted D 6 A (Right). Note that vacuum remelted material is much cleaner



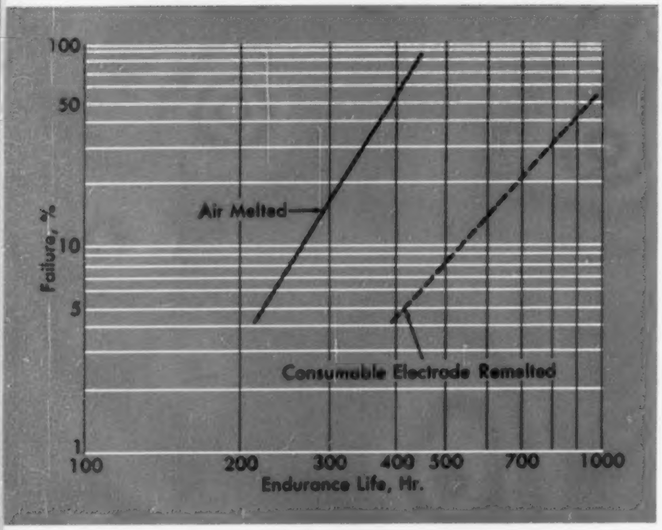


Fig. 2 – Comparison of Endurance Lives of Planetary Pinion Bearings Made of Carburized A.I.S.I. 8620

Note that the weighted factors for air-melted material are considerably less than for consumable-electrode vacuum-melted material. For example, a ⅛-in. indication in air-melted material has a factor of 1, while in consumable-electrode vacuum-remelted material this weighted factor is 256. Obviously, this makes the reduction of specification limits on F/S (from 5/10 for air melting to 0.5/1.0 for consumable-electrode vacuum melting) even greater than is at first apparent.

Despite these more stringent cleanliness specifications, vacuum-melted material has been able to meet the challenge. This is shown by data gathered on an ultrahigh strength steel, commercially known as D 6 AC. Figure 1 shows the statistical distribution resulting from the inspection (by Ladish Co.) of both vacuum-remelted and air-melted heats supplied by three steel producers. (In this study, all heats were rated by the vacuum-melted severity factor so as to maintain a common denominator.) On the consumable-electrode melted material, 83.4% of the 138 tests representing 62 heats met the F/S specification of 0.5/1.0. Such rigid cleanliness requirements on forging billets of vacuum-melted D 6 AC, 300 M, and S.A.E. 4335 V have practically eliminated rejections of missile cases during final magnetic-particle inspection.

Fatigue strength is an example of a property sensitive to cleanliness which is aided by consumable-electrode vacuum melting. This improvement in endurance life has been confirmed by ground tests and flight performance of aircraft engine parts as shown in Fig. 2*. It is generally felt that these increased fatigue strengths are due to the elimination of gross inclusions which, at present, might act as stress raisers.

Vacuum melting also improves impact strength; Figure 3 shows the results of tests on air-melted and vacuum-melted low-alloy steel (A.M.S. 6263 – 0.15 C, 1.5 Cr, 3.25 Ni) as reported by J. E. Thayer and W. McElroy of Curtiss-Wright. The improvement in transverse specimens is especially marked.

Consumable-electrode remelting produces a significant increase in tensile ductility at room and elevated temperatures. Ductility is also improved in superalloys which contain appreciable amounts of elements with high densities and are, therefore, subject to segregation. Figure 4 illustrates micro-segregation in conventionally melted and cast A-286 alloy; this same alloy is free from the M_2Ti phase when it is remelted by the consumable-electrode vacuum-arc technique.

Segregation is minimized by consumable-electrode vacuum melting because of the rapid cooling which occurs in the water-cooled mold of copper. Reducing the segregation aids transverse ductility in A-286, N-155, AM 355, and other alloys. Before consumable-electrode melting appeared, large billet sections of such alloys with a uniform, segregation-free microstructure and a degree of soundness high enough to meet current specifications were extremely difficult to produce.

Titanium Segregation a Problem

In superalloys, which are dependent upon the Ni_3Ti or $Ni_3(Al,Ti)$ constituents for their precipitation-hardened strength (A-286 or Waspalloy, for instance), titanium segregation must be held to a minimum. Figure 5 illustrates the variations in hardness obtained during the aging of A-286 heats with varying titanium contents. In large conventionally cast ingots of alloys of this type, titanium variations as high as 0.40% have often been found throughout the ingot. In consumable-electrode ingots, experi-

*"Quality Aspects in Vacuum Arc Melting", by E. A. Loria, *Blast Furnace and Steel Plant*, June 1957, p. 601-607.

ence has shown that such variations do not exceed 0.15%.

The above examples show how decreasing segregation improves uniformity of properties through length and cross section, and produces good center ductility and good cleanliness.

Parts being employed in jet engine, aircraft, and nuclear reactor components must meet very rigid ultrasonic inspection requirements. Since ingots of many of the superalloys are apt to develop deep pipes, the production of sound billets becomes a problem as ingot size increases. Consumable-electrode remelting, being predicated on incremental melting and solidification, affords close control of solidification variables. Properly handled, this melting process can produce optimum soundness. In actual production runs, this has been proven many times. Rejections of finished parts of large cross sections, such as turbine wheels, have been greatly reduced by using consumable-electrode melted billets for such forgings.

Double Melting Also Helps

Superalloys, such as René 41, have been double vacuum melted to produce large billets or slabs for rolling wide strip. In this instance, the electrodes are produced by induction vacuum melting to gain closer control of chemistry, and are then vacuum-arc remelted to obtain sound, segregation-free ingots.

In another form of double vacuum melting, two successive remelting operations are performed on an air-melted electrode. This is the

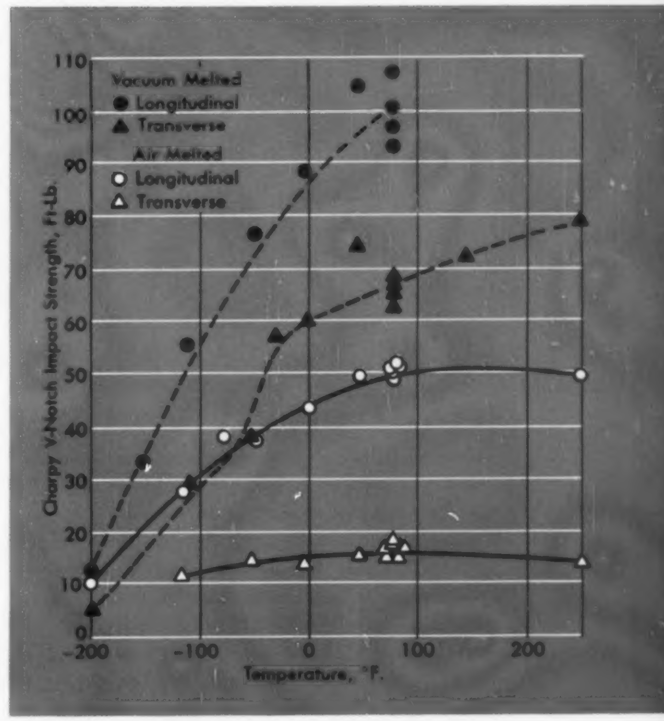


Fig. 3 – Consumable-Electrode Remelting Improves Impact Strength of A.M.S. 6263 (a Chromium-Nickel Steel). This effect is attributed to the absence of nonmetallic stringers

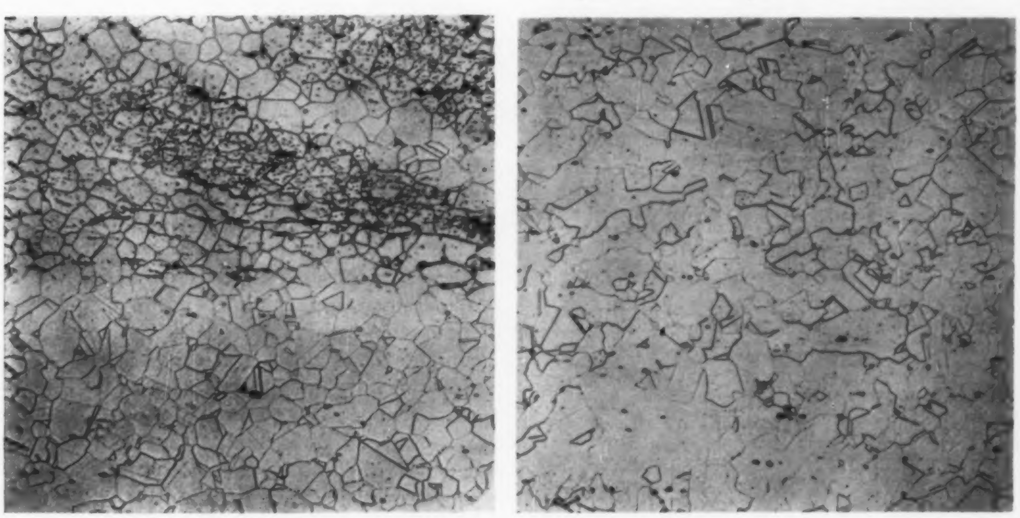


Fig. 4 – Microstructures of Air-Melted (Left) and Vacuum-Melted (Right) A-286. Microsegregation and the M_2Ti phase are virtually eliminated by vacuum melting. Etchant: 10 parts HNO_3, 15 parts HCl, 10 parts acetic acid; 100 ×

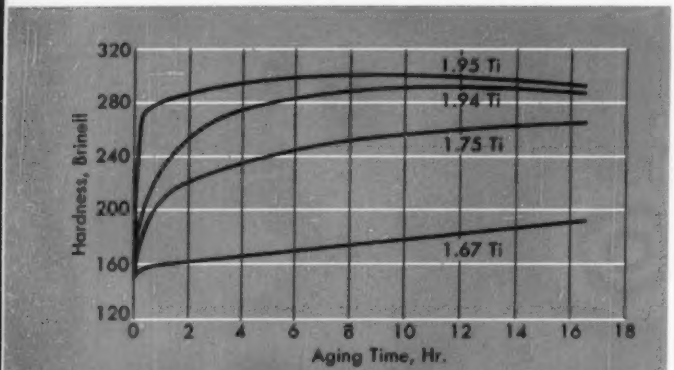


Fig. 5 – Effect of Aging Time on A-286 With Varying Titanium. Before aging (at 1330° F. in air), the specimens were heated at 1810° F. for 1 hr. and quenched in oil. Variations in titanium content throughout an ingot have a great effect on hardness but are minimized by consumable-electrode melting

more economical process of the two, provided that the chemical composition can be adequately controlled during air melting.

We have investigated the effect of double melting (using air-melted electrodes) on the properties of two titanium-bearing superalloys, A-286 and Altemp 901 (42 Co, 13 Cr, 6 Mo, 3 Ti, 0.3 Al, 0.05 C, 0.015 B, balance Fe).

The gas analyses of the A-286 alloy after each melting operation showed these changes:

Gas	Air Melt	Single Vacuum Melt	Double Vacuum Melt
Hydrogen	15 ppm.	1.5 ppm.	1 ppm.
Oxygen	80	21	9
Nitrogen	120	50	20

The stress-rupture properties of A-286 vacuum melts at 1200° F. made from the same master heat were as follows:

	Single Vacuum Melt	Double Vacuum Melt
Time to rupture*	66 hr.	80 hr.
Elongation	16.0%	22.0%
Reduction in area	21.5%	41.0%

*Stress 65,000 psi. for 40 hr., then raised to 70,000 psi. Heat treatment: 1650° F. for 2 hr.; oil quench; 1300° F. for 16 hr.; air cool.

The rupture properties of Altemp 901 at 1200° F. and 90,000 psi. for a heat containing 3.10% Ti were as follows:

	Single Vacuum Melt	Double Vacuum Melt
Time to rupture*	61 hr.	119 hr.
Elongation	5.2%	13.1%
Reduction in area	8.0%	15.7%

*Heat treatment: 2000° F. for 2 hr.; water quench; 1500° F. for 2 hr.; air cool; 1325° F. for 24 hr.; air cool.

It is significant that stress-rupture ductility increased at the same time that stress-rupture life increased in both of the superalloys.

Summary

The consumable-electrode remelting process has firmly established itself in the specialty and fine steel industry in the United States. One of the major accomplishments has been the consistent production of ultrahigh-quality material on a heat-to-heat and a day-in, day-out basis. Often, savings that result from fewer rejections during processing and final inspection will compensate for the premium price paid initially for vacuum-melted alloys. In fact, there have been occasions when such material, though selected originally to improve performance characteristics only, has resulted in a less expensive part as well.

With the increase in ingot size and the experience being gained with large quantity production, the selling prices of a number of steels and superalloys have come down almost 50% in the last two years. Such price reductions are stimulating the use of vacuum-melted steels in the chemical processing industry, land gas turbines, commercial jet engines, airframe components (such as landing gears, engine mounts, and structural parts); for steam turbine bolting, ultraclean rolls (to produce superfinish cold rolled strip), springs and bearings with longer endurance lives, and special components in computers and electronic devices.

In short, the quality performance and growing consumer acceptance of consumable-electrode vacuum-melted alloys make it easy to envision a continuing rapid growth of this process in the coming decade.

Advances in
Vacuum
Technology

Pouring Degassed Steel in an Argon Atmosphere

*By WILLIAM WILSON**

Ingot molds can now be filled with argon, an inert gas 38% heavier than air, to prevent ladle degassed steel from picking up hydrogen, oxygen and nitrogen when it is teemed. The result: Improved macro-etches, fewer inclusions, higher ductilities, and good ingot surfaces. (D9s)

As IS THE SITUATION for all degassing processes in which the molten steel does not stream directly into the ingot mold, we must teem degassed steel in the prevailing atmosphere. When this atmosphere is humid air, degassed steels, although they have a tight stream, can still pick up hydrogen, oxygen and nitrogen.

One method for excluding these gases is "argon teeming", a technique developed by Linde Co. In this process, the air in the ingot mold is displaced with argon, and an argon shroud is provided around the stream while the metal pours into the mold. Argon is used because it is inert to molten steel and has a density 38% greater than that of air.

Ingot Mold Must Be Sealed

When preparing for argon teeming, the ingot molds receive their regular cleaning and inspection, but are then sealed. To accomplish this, several steps must be followed. First, the mating surfaces on the stool and mold are gasketed with asbestos paper (or fiberboard) and silicate cement. Then, the annular gap between the mold and hot top is packed with asbestos rope and covered with a mastic. The hot top opening is covered with a disk of heavy aluminum foil which rests on mastic and is held in place with a steel ring. A flap is cut in the foil to permit the argon diffuser and a gas sampling tube to be inserted. (After the mold is filled, the flap is resealed with tape.)

As a final preparatory step, a "stream protector" is attached to the bottom of the ladle. During teeming, the protector directs argon radially at the stream to form a gaseous shroud.

Operation Is Simple

In our practice, we fill the molds with argon in the teeming order, filling the last mold just before pouring the first ingot. In each mold, the air is displaced by argon flowing from a

*Director of Research and Development, A. Finkl & Sons Co., Chicago.

Fig. 1 – Diffuser Being Removed From Gas-Filled Mold. The oxygen analyzer in the foreground shows that there is virtually no oxygen left in the 34 in. mold

diffuser, lowered to the mold bottom. Using a flow of 3000 cu.ft. per hr. of argon, we fill a 23-in. ingot mold for an 8000-lb. ingot in 30 sec. Figure 1 shows a technician withdrawing the argon diffuser from such a mold. Also shown is a Leeds & Northrup oxygen analyzer – recalibrated for argon – which is used to check the residual oxygen. If filling is done as prescribed, residual oxygen at the top of the ingot mold is always below 0.5%. We find that the atmosphere in a well-sealed mold will contain less than 1% oxygen until the ingot is poured.

Just before teeming, we attach the argon source to the stream protector (see Fig. 2), starting a gas flow 10 sec. before the nozzle is opened. During teeming, 800 cu.ft. per hr. of argon constantly flows from this protector. About 20 cu.ft. of the gas is used per ingot ton; this high consumption results from the low teeming rate which averages 1⅓ ton per min.

Tests on Ingots

Our first tests were with four corrugated ingots (40 in. in diameter, each weighing 17.5 tons), two from each of two heats . On the first heat, the first ingot was air teemed and the second ingot argon teemed. This order was reversed for the second heat.

Samples for gas analyses were cored from the surface, midpoint and center locations of blocks forged from the middle of all four ingots. (We used two samples from each location.) The average gas contents, listed below, definitely show that gas is picked up during teeming in air. Furthermore, the amount would be of concern in critical applications.

Gas	Argon Teeming	Air Teeming
Hydrogen	1.5 ppm.	1.7 ppm.
Oxygen	31	40
Nitrogen	26	37

In another test, etched slices, prepared from each pair of blocks and etched simultaneously, indicated that the argon-poured steel had considerably fewer "freckle spots" (dark spots that indicate discontinuities). Figure 3 illustrates a typical slice.

Cleanliness Is Improved

Inspection by magnetic particle methods is now virtually essential for all superduty steels used in aircraft and missiles. For this purpose, "step" tests are generally used. First, a quarter section immediately adjacent to the product is forged to a 4 in. diameter round. After heat treating, machining to the prescribed depths and finishing, the test bar is circularly magnetized while a suspension of magnetic particles are flowed on the surface. Any longitudinal indications which appear on the machined surfaces are considered to coincide with the

Fig. 2 — *Teeming a 40-In. Ingot in Argon. The stream protector at the ladle bottom keeps air away from the degassed steel by a flow of 1100 cu.ft. per hr. of argon which is started 10 sec. before pouring and continues until the ingot mold has been filled*

inclusion lengths. (Usually, the length represents an aligned group of inclusions which are linked together by the magnetic powder; single inclusions of fractional inch lengths are a rarity.)

Recently, 275 sq.ft. of step-test surfaces were examined from 11 heats melted by the double-slag practice, degassed in the ladle and teemed with argon. Results of magnetic particle inspection showed 4.5 magnetic indications per sq.ft. for inclusions 1/10 to ⅛ in. long; 1.5 for inclusions over ⅛ to ¼ in.; and 0.13 for inclusions over ¼ to ½ in.

Our forge shop reported that each ingot cast in argon had a good surface; these forgings also passed very rigid standards for ultrasonic inspection. As for mechanical properties, tests on a "high side" A.I.S.I. 4340 (silicon and molybdenum were above normal) heat treated to tensile strength ranging from 190,000 to 210,000 psi. had yield strength from 178,000 to 195,000 psi., elongation from 9.5 to 13.5%, and reduction in area from 28 to 43%.

In summary, the argon teeming process gas has been very helpful to us in our continuing efforts to produce better ultrahigh-strength steels. As a consequence, we now couple argon teeming with ladle degassing in making all superduty steels.

Fig. 3 — *Macroetched Slice (18 by 18 in.) of A.I.S.I. 4340, Ladle Degassed and Argon Teemed, Bloom Press Forged From 40-In. Ingot*

Ladle of Steel Being Tapped Into Pony Ladle Preparatory to Vacuum Deoxidation. To make such steels, they are tapped with about 0.05% excess carbon which (at low pressures) combines with oxygen. The resulting carbon monoxide is drawn off during stream degassing

Advances in
Vacuum
Technology

Deoxidizing Steels by Vacuum

*By G. E. DANNER and E. DYBLE**

When unkilled steel is stream degassed in a vacuum, included oxygen will unite with the carbon in the steel, and boil off as carbon monoxide. Extensive tests show that steel deoxidized in this manner (rather than with metallic deoxidizers such as silicon and aluminum) will contain less gases and fewer inclusions. Properties are comparable to those of vacuum degassed steels. (D9s, 1-73, D8m)

To comply with the demands of modern industry, steel producers must continue to improve both product and processes. One such improvement, vacuum stream degassing to reduce gas content (particularly that of hydrogen) of steel, has been used by several steel manufacturers, both here and in Europe, for a number of years. Through its use, we and others have produced many hundreds of tons of prime rotor steel for manufacturers of large electric generators and turbines.

Recently, this now familiar technique has been ingeniously adapted to deoxidize steel in the ladle†. To accomplish this, carbon (in the steel) is employed for deoxidizing instead of the conventional addition of silicon or aluminum. The carbon monoxide, which is formed by the combination of the two elements, is removed under vacuum by steam ejectors.

*Director and Metallurgical Engineer, respectively, Metallurgical and Research Div., Erie Forge & Steel Corp., Erie, Pa.

†The vacuum deoxidation method described in this article is now being patented.

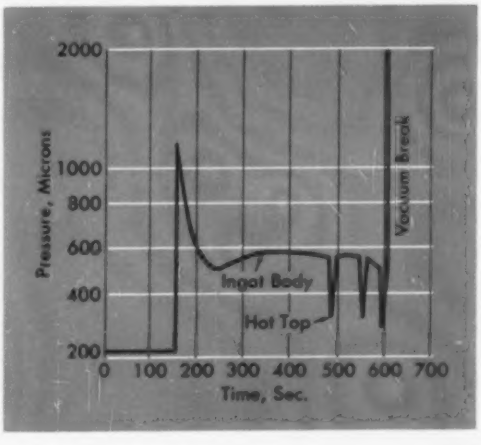


Fig. 1 – Changes in Pressure Which Occur Inside the Evacuated Chamber as a Typical Heat Is Being Degassed and Deoxidized. When the steel has melted the aluminum seal of the chamber, it enters, and the pressure rises abruptly. Then the vacuum system reduces the chamber pressure to a value which remains fairly steady until pouring is finished. (The pressure drops, which occur after the hot top is reached, indicate stream shut-offs.) The vacuum is then broken, and the ingot is allowed to cool in air

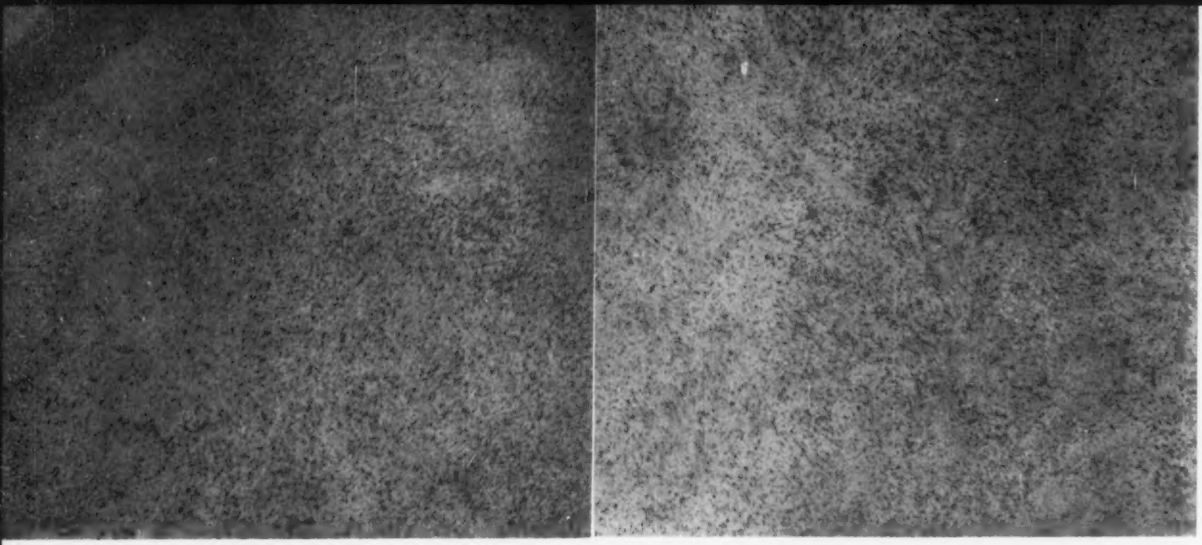


Fig. 2 — Sulphur Prints of Transverse Sections of Vacuum Degassed (Left) and Vacuum Deoxidized Steels. Note that the elimination of metallic deoxidizers in the vacuum deoxidized steel has resulted in a more even distribution of smaller sulphides. Etchant: 2% H_2SO_4; actual size

Initial and Present Practice

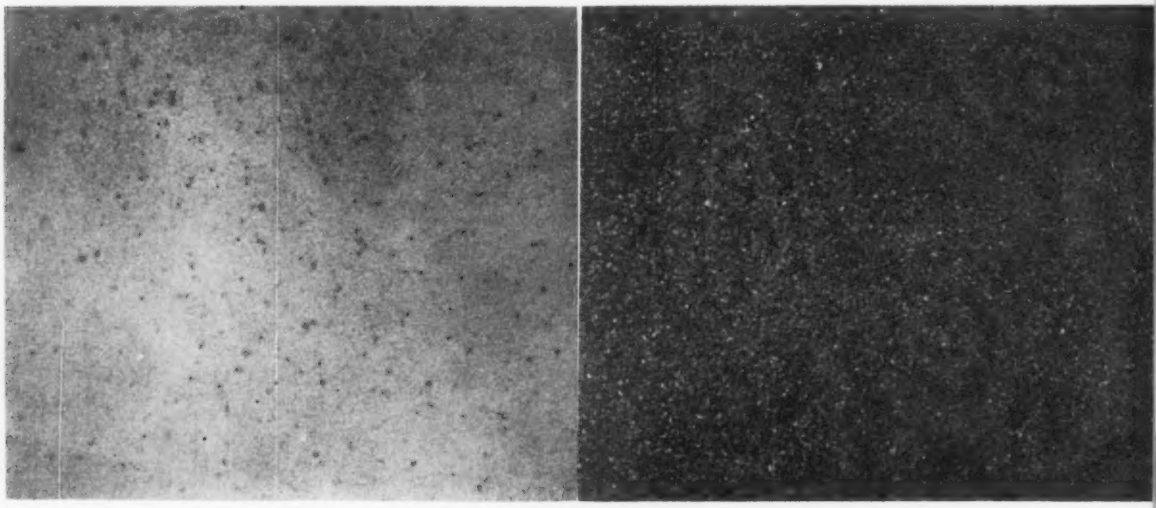
The deoxidizing power of carbon at low pressure has been known for many years. However, the application of stream degassing equipment to deoxidize large heats had not been accomplished in this country until an experimental ingot weighing 35,000 lb. was poured in September 1959, at the instigation of G. A. Taylor, superintendent of Erie's melt shop. Subsequent heats of vacuum deoxidized steel, made under more ideal conditions than the initial heat, proved that these steels are cleaner than steels deoxidized with aluminum or silicon. Our data also indicate that they have less oxygen, hydrogen and nitrogen, and the sulphide inclusions are small and well distributed.

To date, vacuum deoxidized steels have been used in constructing turbine and generator rotors, crankshafts and other forgings. As will be shown later, they have met all specifications for strength, cleanliness, and segregation.

Details of the Process

Steels for vacuum deoxidation have been made in both the acid openhearth and the basic electric furnace. Let us describe the working of a typical electric furnace heat. After scrap and burnt line are added, the charge is melted with

Fig. 3 — Transverse Sections of Vacuum Degassed (Left) and Vacuum Deoxidized Steels Etched in Hot Acid. Here, as in Fig. 2, the vacuum deoxidation process appears to have resulted in a more even distribution of smaller inclusions. Etchant: 50% HCl in H_2O; actual size



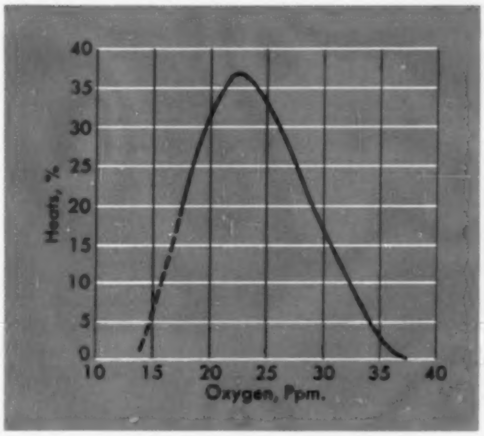


Fig. 4 — Variations in Oxygen Content of Several Heats of Vacuum Deoxidized Steel

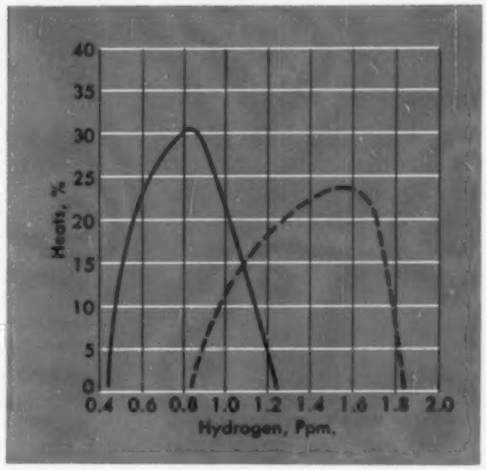


Fig. 5 — Hydrogen Contents of Vacuum Deoxidized Steels (Solid Line) Compared With Those of Vacuum Degassed Steels (Dashed Line). As is apparent, most vacuum deoxidized heats contain less than 1 ppm. hydrogen

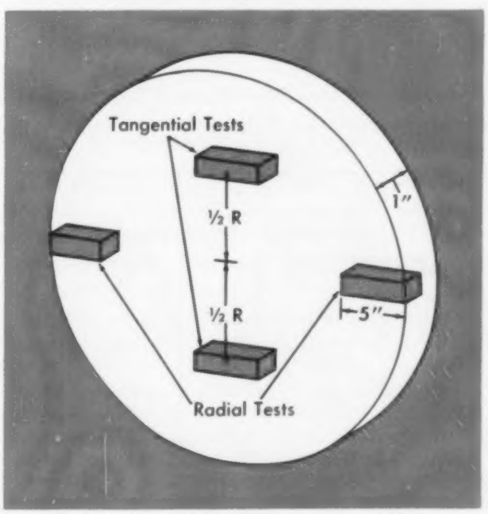
carbon 0.20 to 0.25% higher than the required maximum needed at tap. Then ore is added, and oxygen is used to bring the carbon down to within 0.05% above required maximum. After the oxidizing slag is removed, a reducing slag is charged, nickel and molybdenum being added (when required for alloy steels) during the oxidizing period.

When the reducing slag is in the proper condition, ferroalloys of manganese, chromium and vanadium (as required) are added. To keep the silicon content at a minimum, low-silicon ferroalloys are used. If necessary, the carbon content is adjusted, and the heat is tapped 30 min. after the addition of the ferroalloys. No metallic deoxidizer is used.

After tapping the heat, the furnace ladle is positioned over a pony ladle (see photograph on p. 74) which is mounted on a previously evacuated chamber (29 ft. high by 17 ft. in diameter) containing the ingot mold. Metal pours from the furnace ladle into the pony ladle filling it to about the three-quarter mark. At this point, the stopper of the pony ladle is opened. Liquid metal pouring from the nozzle melts the aluminum seal of the evacuated chamber and is degassed and deoxidized as it pours into the ingot mold. The carbon in the steel reacts with dissolved oxygen to form carbon monoxide. During the reaction, carbon drops about 0.05% to come within chemical specifications.

Figure 1 illustrates the pressure variations which occur in the vacuum chamber as a heat is being poured. When the stream enters the mold, the pressure rises abruptly from about 200 microns to over 1000 microns, and then levels off between 500 and 600 microns. Though outgassing is greater for vacuum deoxidation than for vacuum degassing (because of the extra carbon monoxide), the ejector system has sufficient capacity to take the extra gas volume. When the ingot is poured to the required height in the hot top, the vacuum chamber is pressurized to atmospheric pressure by opening a valve. The top of the chamber is then re-

Fig. 6 — General Locations of Radial and Tangential Test Bars



moved, and the ingot is permitted to solidify in air.

Vacuum Deoxidation

Since no metallic deoxidizers are used, there is a direct decrease in the quantity of nonmetallic inclusions. This is apparent in the sulphur prints shown in Fig. 2. As further evidence of the improvement in inclusion distribution and size, Fig. 3 illustrates transverse slices of forged sections etched in hot hydrochloric acid.

The gas content is also lowered. In general, oxygen contents in vacuum deoxidized steels vary between 20 and 30 ppm., as shown by Fig. 4. Hydrogen contents of vacuum deoxidized steels also appear to be lower than those of vacuum degassed steels. In fact, Fig. 5, which shows a plot of comparable hydrogen values, indicates that hydrogen contents of deoxidized heats vary between 0.4 and 1.2 ppm. while degassed steels have from 0.8 to 1.8 ppm. hydrogen.

Nitrogen is also lowered by vacuum deoxidation. Results showed that it varies between 10 to 30 ppm., as compared to amounts of 40 to 70 ppm. for vacuum degassed steels of the same composition.

Mechanical Properties

Table I shows that tensile, ductility and impact properties of vacuum deoxidized steels are comparable to those of vacuum degassed steels. This table lists mechanical properties obtained from rotors made from a split heat of alloy steel. (Figure 6 shows the general locations of the test bars.) The steel for Rotor "B" represented half of one heat; it was tapped from the furnace before deoxidation and deoxidized in vacuum. Meanwhile, the other half of the same heat (the steel for Rotor "A") was deoxidized with silicon, and degassed in the chamber. Table II lists pertinent analyses. These steels have passed all property and cleanliness requirements of rotor manufacturers.

Table I – Properties of Vacuum Treated Steels*

	Rotor A Vacuum Degassed	Rotor B Vacuum Deoxidized
Tensile strength	106,000 psi.† (*105,200*)	100,700 psi. (*105,200*)
Yield strength	87,500% (*86,900*)	83,750% (*86,900*)
Elongation in 2 in.	22.2% (*20.2*)	22.2% (*22.0*)
Reduction in area	56.8% (*51.6*)	60.0% (*56.5*)
Charpy V-notch impact		
75°	45.5 ft-lb.	52.5 ft-lb.
175°	88.5 ft-lb.	92.0 ft-lb.

*Tests represent properties of rotors made from a split heat; rotor compositions are shown in Table II.

†Radial and tangential values are given for an average of two tests. (Tangential values are in italic.)

In Conclusion

Briefly, we believe that the vacuum deoxidation process, with its ability to produce steels with fewer inclusions and smaller amounts of gas, has a bright future. As a consequence, in addition to using the technique to pour steel for generator and turbine rotors, as we do now, we expect to apply it to the production of steel for rolled products and forgings of all sizes.

Table II – Chemical Composition of Vacuum Treated Steels*

	Rotor A—Vacuum Degassed					Rotor B—Vacuum Deoxidized				
	Heat Analysis V1EF567	Ingot Top		Ingot Bottom		Heat Analysis V1EF567	Ingot Top		Ingot Bottom	
		Center	Surface	Center	Surface		Center	Surface	Center	Surface
Carbon	0.23	0.22	0.23	0.20	0.20	0.20	0.22	0.22	0.23	0.23
Manganese	0.63	0.57	0.56	0.57	0.58	0.55	0.56	0.57	0.57	0.56
Phosphorus	0.010	0.012	0.012	0.013	0.012	0.008	0.012	0.010	0.011	0.011
Sulphur	0.015	0.016	0.014	0.017	0.014	0.015	0.018	0.016	0.014	0.014
Silicon	0.20	0.13	0.14	0.14	0.14	0.2	0.012	0.014	0.015	0.015
Nickel	3.05	3.05	3.06	3.05	3.04	3.09	3.05	3.06	3.06	3.07
Chromium	0.25	0.25	0.25	0.26	0.25	0.25	0.25	0.24	0.24	0.24
Vanadium	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.07	0.08	0.07
Molybdenum	0.36	0.35	0.35	0.37	0.36	0.35	0.35	0.35	0.36	0.35

*These are analyses of a split heat; for mechanical properties see Table I.

Helicopter Powered by Two Gas Turbine Engines

AM355 for Gas Turbine Engines

*By PAUL A. BERGMAN**

AM 355, a controlled-transformation stainless steel, offers an excellent combination of the better features found in the 300 and 400 series. This article discusses general characteristics and properties of AM 355 forgings and bar stock, including the effects of retained austenite and its control. (A-general, T24b, Q-general; SS)

SMALL GAS TURBINE ENGINES DEVELOPED for missiles, aircraft, and helicopters have recently been introduced in marine and industrial applications. Some of the materials originally used in highly stressed rotating parts in the compressor section appeared to be inadequate as more corrosive environments were encountered and higher strengths were required. AM 355 offers a definite improvement and promise of meeting these requirements. It is being used for many compressor parts such as blades, disks, spool rotors, spacers, seals and shafts (see Fig. 1). Blades are rolled from bar stock, and the other parts are machined from forgings.

AM 355 is a controlled-transformation stainless steel which occupies a position between the 400 (martensitic) and 300 (austenitic) series with respect to chemistry and corrosion resistance. Depending on thermal treatment, it has

*Metallurgical Development Engineer, Small Aircraft Engine Dept., Thomson Engineering Laboratory, General Electric Co., Lynn, Mass. The author wishes to acknowledge the assistance of G. Mohling, R. Lula, W. Dyrkacz, G. Aggen, A. Graae, F. Hackett and many others at Allegheny Ludlum Steel Corp. Also, the author is grateful for the advice and encouragement of G. V. Cash of Thomson Engineering Laboratory. The discussion and review of this paper by A. E. Palty and the cooperation of many other members of the Small Aircraft Engine Dept. is appreciated.

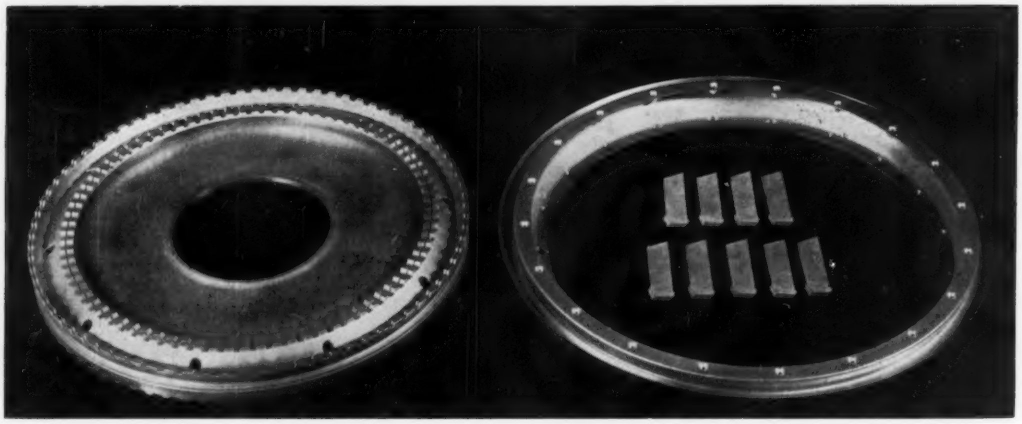


Fig. 1 – Typical AM 355 Compressor Parts for Gas Engines Include a Disk (Left), a Spacer (Right) and Blades Within the Spacer

an austenitic or a martensitic microstructure. Note in Table I that Type 302 has a higher alloy content and resistance to salt-spray corrosion than Type 403, with AM 355 in a position between the two. The elements contributing to corrosion resistance – chromium, nickel and molybdenum – are unusually high in AM 355, considering that it can be transformed to the martensitic condition.

Because of its stress-corrosion resistance and good notch ductility, AM 355 (in the martensitic condition) can be used at higher hardnesses than Type 403 and modifications of Type 403. Thus, the alloy can achieve an excellent combination of mechanical properties and corrosion resistance with proper heat treatment.

Heat Treatment of AM 355

In the annealed condition, AM 355 has properties similar to the austenitic stainless steels, but unlike them, it can be hardened by martensitic transformation.

To impart maximum ductility and minimum strength – for forming operations at room temperature – AM 355 is heated to 1950° F. and then cooled at a rate sufficiently fast to prevent carbide precipitation. The high solution temperature dissolves all carbides and imparts maximum austenite stability at room temperature. Figure 2 shows the effect of solution temperature on M_s temperature – the higher the solution temperature, the lower the M_s temperature.

In fabricating compressor blades by rolling, a working range of 200 to 300° F. is more desirable than room temperature since the tendency to form martensite through work hardening is decreased at elevated temperatures.

For high strength and adequate ductility AM 355 is heat treated to a tempered martensitic structure. The following subzero cooling and tempering (S.C.T.) treatment is used:

2 hr. at 1425° F., air cool

1 hr. at 1700 to 1750° F., oil quench

3 hr. minimum at −100 to −120° F.

Temper 3 hr. at 1000° F. (Rockwell C-27 to 44); air cool.

Table I – Chemical Composition and Corrosion Resistance of Three Types of Stainless Steel

Material	Structure	Composition					Relative Corrosion Resistance in Salt Spray
		C	Cr	Ni	Mo	N_2	
Type 403	Martensitic	0.15 max.	12.5	—	—	—	Borderline
AM 355	Annealed, austenitic						
	Heat treated, martensitic	0.12	15.5	4.5	3.0	0.10	Very good
Type 302	Austenitic	0.15	18.0	9.0	—	—	Excellent

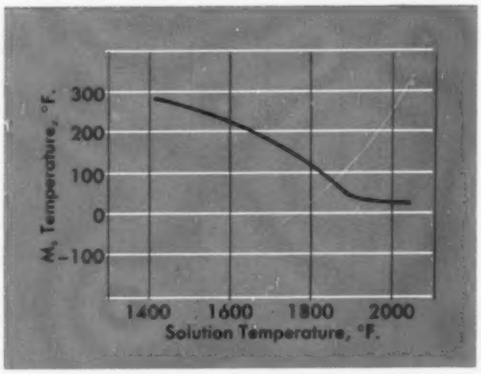


Fig. 2 – Effect of Solution Temperature on M_s Temperature of AM 355

The treatment at 1425° F. is a presolutioning cycle which promotes a more uniform distribution of carbides during the solutioning at 1750° F. and more complete transformation to martensite during subzero cooling. This pretreatment is essential, particularly in heavy bars and forging stock, where inhomogeneities in structure and chemistry arise from the high forging and process-anneal temperatures, and the relatively small amount of hot and cold work imparted.

A solution treatment at 1700 to 1750° F. is used to condition the alloy for the martensitic transformation. There is partial solubility of carbides at these lower temperatures (compared to the 1950° F. treatment) resulting in an M_s at or slightly above room temperature. Subzero cooling completes the transformation. Lower solution treatments result in a heavier precipitation of carbides and a higher M_s temperature. However, the highest practical solution temperature is preferred to develop a high-carbon martensite for optimum strength and ductility.

Tempering – Although the highest strength is obtained with a temper at 850° F., 1000° F. is preferred because of improved ductility and less notch sensitivity. Tempering at 1000° F., compared to 850° F., has a pronounced effect on properties and machinability. Hardness is lowered from Rockwell C-42 to 52 to Rockwell C-37 to 44 with a resulting decrease in ultimate, 0.2% yield, and stress-rupture strength. However, the proportional limit increases slightly, tensile elongation is raised from a range of 6 to 20% to a range of 12 to 25%, fatigue strength increases from 70,000 to 90,000 psi., impact strength increases from a range of 6 to 21 ft-lb. to a range of 20 to 50 ft-lb., and stress-corrosion resistance is improved considerably. The lower hardness and strength also reduces the machining costs.

Corrosion Resistance Is Good

In many applications, AM 355 has replaced alloys such as Greek Ascoloy, Type 403 stainless and A.I.S.I. 4340 because of its superior corrosion resistance. Protection of the latter alloys by various paints or ceramic and metallic coatings is of limited value because of erosion, tolerance variations in thin coatings, and mechanical damage to the coating.

A fatigue testing program was completed to determine the effects of salt-spray corrosion on Type 403, Greek Ascoloy, and AM 355 at various hardness levels. We tested one group of Krause fatigue specimens in the dry condition; a second group was precorroded for 150 hr. in a 5% salt fog; the third group was tested in a 5% salt spray. Initial surface finishes were comparable for all specimens. Results are summarized in Table II. Precorroding significantly reduces the fatigue strength of Type 403 and Greek Ascoloy, but has no effect on AM 355. The low strength of 38,000 psi. for Type 403 and Greek Ascoloy is equivalent to their notch-

Table II – Corrosion-Fatigue Data for Several Alloys

Material	Rockwell Hardness	Fatigue Strength (10^8 Cycles)		
		Normal	Precorroded 150 Hr. in 5% NaCl	5% NaCl Spray During Testing
Type 403	C-24	68,000 psi	38,000 psi	12,000 psi
Type 403	31	78,000	38,000	12,000
Greek Ascoloy	34	73,000	38,000	14,000
AM 355	42	88,000	88,000	38,000

fatigue strength (stress-concentration factor, $K_t = 2.5$) in a conventional dry test.

The salt spray directed on the specimens during testing drastically reduced the fatigue strengths of all three alloys, even compared to the results of the precorroded specimens. However, the 38,000-psi. fatigue strength of AM 355 is considerably higher than the 12,000 and 14,000-psi. fatigue strengths of Type 403 and Greek Ascoloy.

Resistance to Stress Corrosion

Type 403, which is known to have satisfactory resistance to stress corrosion, was selected as the comparison material in testing AM 355. Strip stock of both materials, stressed to 85% of the 0.02% yield strength in bend-type fixtures, was tested in a 20% NaCl fog and a $HCl\text{-}SeO_2$ solution. These were the results:

	Type 403	AM 355
Rockwell hardness	C-26	C-38 to 40
Applied fiber stress	86,000 psi.	126,000 psi.
Results in $HCl\text{-}SeO_2$	2¼ hr. cracked	45 and 157 hr. cracked*
Results in 20% NaCl	1000 hr. no failure†	1000 hr. no failure

*Specimens were subjected to severe etching, resulting in deep crevices as early as 29 hr., which reduced the fiber stress.

†Specimens had deep crevices, which reduced the fiber stress.

The AM 355 is more resistant to failure than Type 403 in the $HCl\text{-}SeO_2$ solution. Neither material failed in 1000 hr. in the 20% NaCl fog. However, AM 355 harder than Rockwell C-45 may be subject to failure in a very short time and should be used with discretion.

Results of Tensile Tests

Tensile tests on more than 200 forgings reveal isotropy of tensile properties in the I.D. radial and O.D. tangential directions. Table III gives the tensile results on a pancake forging. In this particular forging, even the tensile results in an axial direction compare favorably with the results in the radial and tangential direction. The ratio of ultimate tensile strength of a standard notched specimen to a smooth specimen is 1.5 – a good indication of the toughness of AM 355.

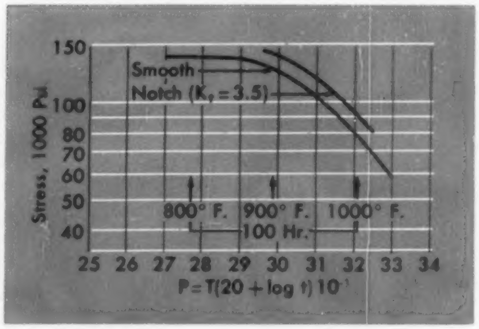


Fig. 3 – Smooth and Notched Stress-Rupture Data for AM 355

There is generally less than 10% ferrite in AM 355, which has very little effect on longitudinal and transverse tensile properties, as indicated by the tests mentioned above. In agreement with these results, data indicate that AM 350 (an alloy very similar to AM 355) in sheet form and containing 10 to 20% free ferrite is essentially isotropic with respect to tensile properties. However, limited impact data on AM 355 show some loss of ductility in the transverse direction.

The smooth and notch stress-rupture values, plotted in Fig. 3, show AM 355 to be notch ductile; that is, the notch-rupture life is greater than the smooth-rupture life. Smooth and

Table III – Tensile Data for an AM 355 Pancake Forging

Direction	Test Temperature	Ultimate Strength	Yield Strength, 0.2% Offset	Elongation	Reduction in Area
Tangential	Room	191,600 psi.	175,600 psi.	17%	53%
Radial	Room	190,300	176,300	17	45
Axial	Room	193,500	169,500	19	43
Tangential	400° F.	171,300	160,600	15	51
Radial	400	168,700	156,600	13	49
Axial	400	164,000	—	14	47
Tangential	600	164,800	149,000	14	52
Tangential	800	160,100	138,800	14	47
Tangential	1000	120,000	107,000	18	54

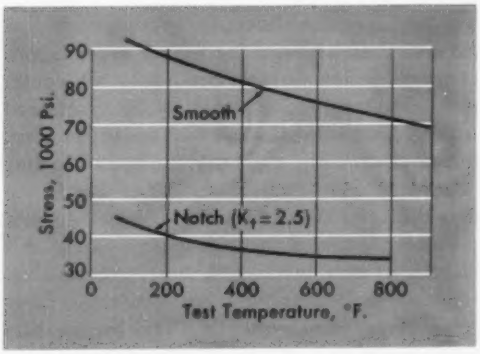


Fig. 4 – Fatigue Strength (10^8 Cycles) of AM 355 versus Temperature

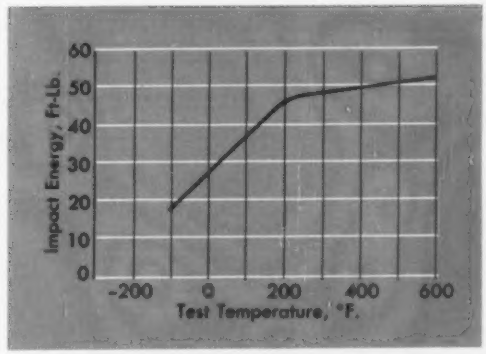


Fig. 5 – Charpy V-Notch Impact Strength of AM 355 versus Temperature

notch fatigue properties, plotted in Fig. 4, indicate the notch-fatigue sensitivity is comparable to that for Type 403 (Rockwell C-20 to 26) which is considered satisfactory. Typical impact values, plotted in Fig. 5, reveal high impact strength for AM 355, even at temperatures as low as −100° F.

To summarize, AM 355 exhibits excellent notch ductility at hardnesses of Rockwell C-37 to 44 and is therefore not likely to fail prematurely as a result of high stress concentration at notches.

Alloy Stability

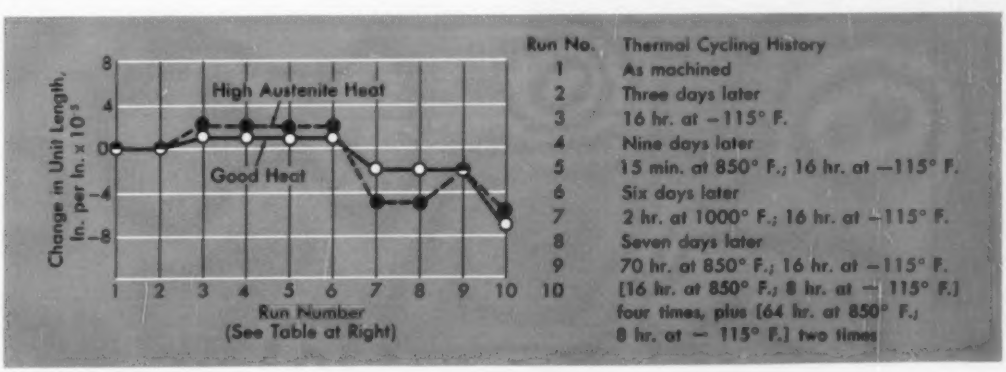
A high degree of alloy stability is needed to prevent changes in clearances and rotor balance, and also changes in microstructure that might result in embrittlement.

A normal production heat of AM 355 containing less than 15% retained austenite, well-dispersed, and a heat containing about 50% retained austenite (unacceptable quality) were selected to determine the influence of temperature cycling on the dimensional stability.

The cumulative dimensional changes resulting from various time-temperature cycles are plotted in Fig. 6. A growth would be associated with the transformation of retained austenite to martensite, which could have an embrittling effect (untempered martensite). Length increases of 0.00002 and 0.00003 in. per in. were observed in the high austenite specimen and 0.00001 in. per in. in the normal specimen; these are insignificant. The *shrinkage* values obtained (after some of the 850 and 1000° F. cycles) are probably associated with the agglomeration of carbides and the precipitation of nitrides. This shrinkage would be offset by small amounts of creep during engine operation at high temperature. AM 355 is generally used at temperatures below 750° F., which would minimize this shrinkage.

To determine whether an embrittlement phenomenon exists, tensile specimens were tested

Fig. 6 – Dimensional Stability of AM 355, Exposed to Various Thermal Cycling Conditions



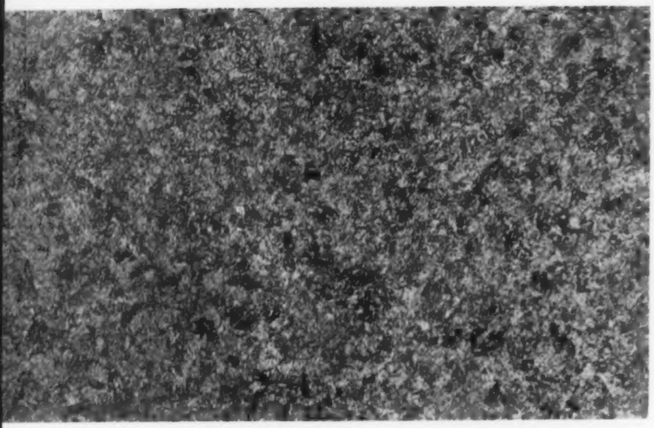


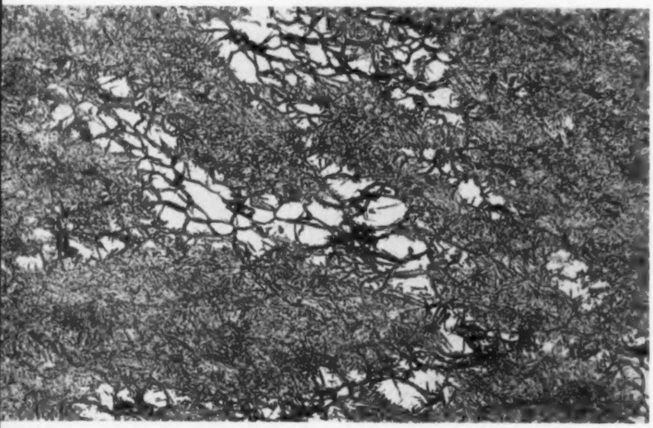
Fig. 7 – A Martensitic Structure in a Consumable-Electrode Melted Heat of AM 355. No distinguishable retained austenite present. Etchant: HCl-picral. 100 ×

at room temperature after cycling between +800 and −100° F. The results (Table IV) show that the cycling treatment increases the ultimate and yield strengths, but does not affect ductility significantly.

Control of Retained Austenite

In initial applications, air-melted AM 355 was used. After a complete heat treatment, large areas of retained austenite were found. This was due to segregation of chromium, nickel,

Fig. 8 – Two-Phase Structure in a Segregated, Air-Melted Heat of AM 355. The light phase is retained austenite and the dark acicular phase is martensite. Etchant: HCl-picral. 100 ×



and probably molybdenum, predominantly at the center and toward the top of larger ingots. The segregation carried through to the center of finished forgings, and showed up as retained austenite, regardless of the heat treatment tried. It is not surprising, then, that the homogenizing treatments were ineffective; this is due to the slow diffusion rates of the segregated elements.

Figures 7 and 8 are photomicrographs of a sample from a production heat (consumable-electrode melted) and of a heat containing large areas of retained austenite. The former normally contains less than 15% of well-dispersed retained austenite. Large segregated areas of retained austenite (Fig. 8) have no effect on hardness, room-temperature ultimate, 0.2% yield strength, or tensile ductility, but the proportional limit and 0.02% yield strength are considerably reduced. To explain these results opposing forces must be considered, such as *(a)* the lower strength of the austenite, *(b)* growth due to formation of new martensite (work hardening) and *(c)* increase in strength due to the formation of the new martensite. At lower stresses the first two factors dominate; at higher stresses the latter factor dominates.

Retained Austenite Influences Creep

Table V gives the results of interrupted creep tests for a normal austenite heat and a high austenite heat of AM 355. Data for B5F5 (low-alloy steel containing 0.45 C, 0.95 Cr, 0.55 Mo and 0.30 V), Type 304 stainless and the precipitation-hardening austenitic alloy A-286 are included for comparison.

We found that large amounts of retained austenite have a profound effect on creep characteristics. The high-austenite AM 355 heat (at 130,000 psi. for 1 hr. and 100 hr.) had a greater total extension at room temperature than at 500° F. This is due to transformation of austen-

Table IV – Effect of Thermal Cycling on AM 355 Tensile Properties*

	0 Cycles	15 Cycles
Ultimate strength	185,300 psi.	203,300 psi.
Yield strength, 0.2% offset	176,400	196,700
Elongation	17.0%	16.5%
Reduction in area	51.0	49.5

*Specimens were heated to 800° F. and held overnight or over a weekend, then cooled to −100° F. and held 2 hr.

Table V – Low Temperature Creep Data for Some Alloys

Material	Test Temperature	Stress	Total Plastic Deformation, In. per In. × 10^{-6}		
			5 Min.	1 Hr.	100 Hr.
Type 304	Room	27,000 psi.	206	242	358
A-286	Room	103,000	602	1051	1111
B5F5	Room	130,000	—	12	54
	500° F.	130,000	694	808	1110
Normal AM 355	Room	130,000	—	12	20
	500° F.	130,000	35	39	64
High-austenite	Room	130,000	71	104	185
AM 355	500° F.	130,000	78	84	107

ite at room temperature (work hardening) which produces growth. This factor far outweighs any strengthening due to the newly formed martensite. At 500° F., no transformation takes place.

At room temperature, the total extension of the high austenite material is considerably greater than the extension of the normal material. There is a much smaller difference between these two heats at 500° F.

Improved melting techniques eliminated the segregation problem. When various modifications in the air-melting process were found to be only partially successful, consumable-electrode melting was specified and excellent results were obtained. Although melting by the consumable-electrode method is in a large part responsible for minimizing retained austenite, the following factors are also helpful:

• Finishing the forging operation at a temperature of 1800° F. or lower, which produces austenite that is easier to transform (higher M_s).

• Employing a presolution treatment at 1425° F. (see recommended procedure p. 80), which promotes a more uniform response to subsequent heat treatment.

• Using a rapid, nondestructive eddy current test, which verifies control of retained austenite in finished parts. This test is necessary since hardness testing does not indicate excessive austenite due to faulty heat treatment, such as an incomplete subzero cool.

• Controlling the homogeneity of the stock with a rapid production test.

In trying to develop a rapid production test, we found that tensile testing for 0.02% yield strength was not satisfactory because of difficulties in obtaining accurate values; creep testing was time consuming, equipment was limited and microexamination was too cumbersome for checking large quantities of material. The following macroetch test was devised: A specimen is immersed for 20 to 30 sec. in a water solution of 40% HCl and 20% HNO_3 at 160° F. If any white areas are found, the material is rejected due to excessive retained austenite (see Fig. 9).

In summary, with the retained austenite problem finally under control, AM 355 has reached maturity and is now considered a satisfactory production material for many applications.

Fig. 9 – Macroetch Test on Half of a Radial Slab of a Forging From a Segregated, Air-Melted Heat of AM 355. The light, unetched areas are retained austenite. Segregation of this type is cause for rejection. Etchant: 40% HCl, 20% HNO_3 in water. ½ ×

A.S.M.'s President for 1960-61

William Alvin Pennington
Professor and Head of Metallurgy
University of Maryland

WILLIAM ALVIN PENNINGTON, the genial and breezy 41st president of the A.S.M., was born in Halls, Tenn., about 75 miles northwest of Memphis. After receiving his bachelor degree in 1925 from Union University in Jackson, he taught chemistry and was the principal of Spring Hill High School, Trenton, Tenn. Returning to college, he was a graduate assistant at Iowa State College from 1929 to 1933 (when he got his doctor's degree) and an instructor in chemistry and metallurgy from 1933 to 1934. He then returned to his alma mater, Union University, as head of the department of mathematics.

Bill soon turned his attention to industry and became research engineer at Armco Steel Co. from 1935 to 1940; industrial fellow at the Mellon Institute, in charge of fellowship on foundry practice, 1940 to 1944; and chief chemist and metallurgist, Carrier Corp., 1944 to 1954. Since 1954 he has been professor and head of metallurgy at the University of Maryland, where he supervises and teaches the only undergraduate and graduate curriculums offering degrees in metallurgy in the Washington, D.C., area.

Bill is a member of many organizations – Phi Lambda Upsilon, Alpha Chi Sigma, Sigma Xi, Alpha Sigma Mu (honorary member), American Chemical Society, Fellow of American Assoc. for the Advancement of Science, Faraday Society, American Society of Refrigerating Engineers, American Institute of Chemists, American Institute of Chemical Engineers, American Institute of Mining, Metallurgical and Petroleum Engineers, and most probably others that have not been tracked down. Though he has been active in many of these organizations, his real love is the American Society for Metals, to which Bill has unselfishly given many years of loyal and devoted service. He was chairman of the Syracuse Chapter, 1948-1949; member of the publications committee from 1948 to 1950 and its chairman in 1951; member of the nominating committee, 1949; chairman of the Howe Medal Committee, 1952; chairman of the finance committee and treasurer, 1953 to 1955; vice-president, 1959-1960 and, of course, is now president. As committee chairman, he has helped to complete the tremendous task of formulating definitions of terms relating to metals and metalworking for the new Metals Handbook. The efficiency with which he tackled this job was a tribute to his executive ability, tact and physical energy. As if this were not enough, he also served as chairman on three other handbook committees.

The new president of A.S.M. has a keen and active mind that enables him to cut through the camouflage that obscures many situations and to come directly to the crux of a problem. Having arrived there, he is never satisfied until the problem has been fairly and honestly resolved. Bill's most outstanding characteristic is a desire for truth that amounts almost to a religious crusade. He is absolutely unyielding to what he thinks is wrong and fights uncompromisingly for what he thinks is right. No obstacle is too great if he feels that the cause is just. During his term of office, it is certain that the affairs of the Society will receive his most careful and conscientious attention in his search to modify or eliminate that which he finds to be wrong, and to improve and strengthen that which he believes is right.

Bill has tremendous physical power and drive, and apparently he has had this all his life. When only 11 years old, he began plowing behind two husky mules who surely must have been worked to death. At 15 he spent his first of five summers in a timber camp in the Mississippi bottom pulling on a cross-cut saw. The working hours were long, 10 to 11 per day, with temperatures as high as 100° F. He often jokes about this work, saying that those two stubborn mules and that inanimate saw literally drove him into college for a taste of a different, if not better, life.

There was a time when Bill was quite an athlete. In high school he played baseball and also played on the basketball team known as the Halls High Tigers, which was famous throughout Tennessee. In college he played tennis, handball, and football. He fancied himself as a high-class handball player until recently when he tangled with a real pro. The licking he took reduced him to gardening as a major form of athletics.

As mentioned before, the four years between graduating from Union University and entering Iowa State were spent as principal and teacher at Spring Hill High School. In addition to teaching six classes each day and discharging his responsibilities as principal, he coached both boys' and girls' basketball, and in 1928 the girls' team placed third in a state tournament. This despite the fact that the school didn't even have a gymnasium! Bill was also director of calisthenics and coached and presented all school plays, presumably in his spare time.

Bill is a skilled and polished speaker. He has the knack of embellishing a serious talk with humorous facets that makes for pleasant and instructive listening. He is the author of numerous contributions to the technical literature, the high quality of his researches in metallurgy being nationally recognized in 1947 when he was awarded the Henry Marion Howe medal of the A.S.M. for his paper, "A Mechanism of the Surface Decarburization of Steel". An expert in the field of refrigerants, he invented Refrigerant 500, the only commercial azeotropic refrigerant used today.

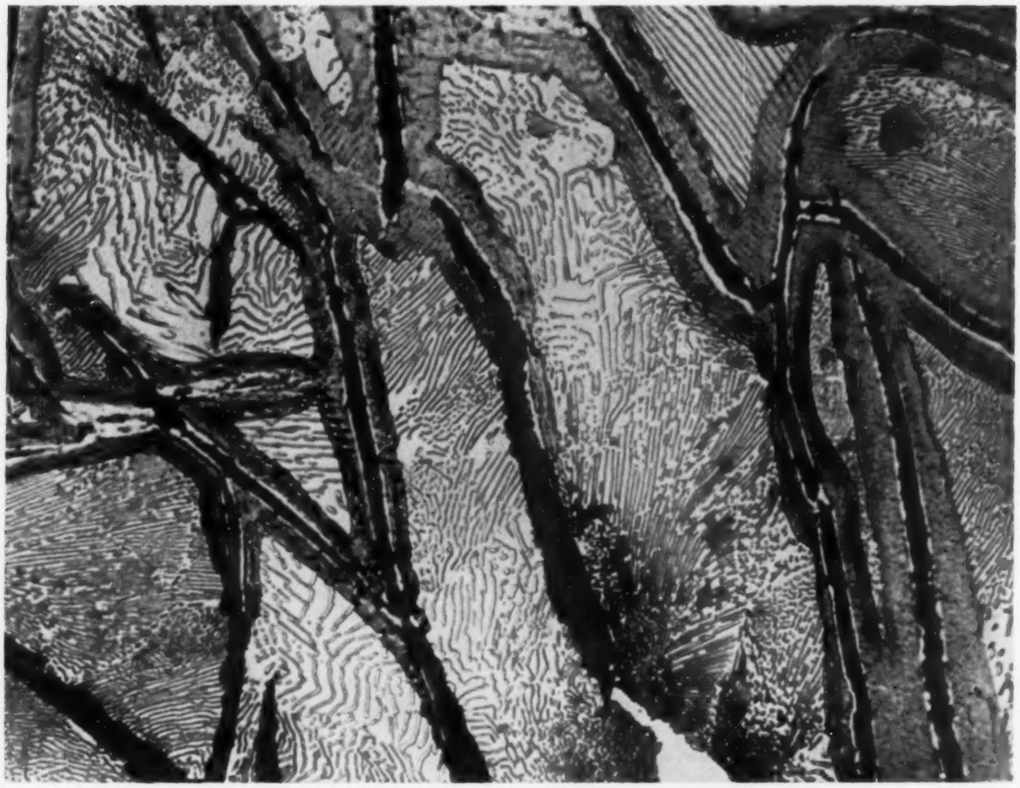
As a loyal member of the Washington Chapter, A.S.M., he attends chapter meetings regularly except when national A.S.M. business takes him out of town. After viewing the recent presidential inauguration, the members of the Washington Chapter are toying with the idea of having a band on hand to play "Ruffles and Flourishes" and "Hail to the Chief" everytime Bill comes in. We think he rates it.

SAMUEL J. ROSENBERG

Grand Prize

15th A.S.M. Metallographic Exhibit

to Gordon C. Woodside, Climax Molybdenum Co. of Michigan



"Heat Checked" Permanent Mold of Unalloyed Gray Iron, Showing Oxidation Along Graphite Flakes Which Formed Layers of Ferrite and an Fe-FeO Eutectoid. Polishing procedure: Rough grinding 180-grit silicon carbide paper. Medium grinding through 0, 00, and 000 emery paper. Final polishing: Step one – Miracloth wheel impregnated with 3-micron diamond polishing compound. Step two – Miracloth wheel impregnated with 1-micron diamond polishing compound; carbon tetrachloride lubricant was used; room well ventilated. Etched with 4% picral; original magnification 1000 ×; reduced to 650 ×

The judges' choice was based on the following considerations: Because of the wide range in hardness of the various phases present, the work required the most careful techniques from first to last. None of the soft particles had been pulled out during polishing. Photographically, the micro was beyond criticism, and enough tones were reproduced to reveal structural details clearly and sharply. The sample itself was quite out of the ordinary and the micrograph was esthetically pleasing.

Sintered Iron Piston Rings

*By ROBERT TALMAGE**

Sintered iron rings are stronger and more wear resistant than cast iron rings and in addition are self-lubricating. They have a cleaner, more uniform microstructure and can be produced at lower cost. (T7, 17-57; Fe, 6-72)

A PISTON RING, ALTHOUGH IT LOOKS VERY SIMPLE, is actually a very complex article to manufacture. Cast iron has been the standard material for 50 years, and the manufacture of piston rings has been highly refined (including automation) over the years to keep costs as low as possible and satisfy engine requirements. Today's product is about the ultimate, however, and any significant improvement must come from some other process.

Advantages of Sintered Iron

There are four areas where improvement can be made: *(a)* uniformity of material, *(b)* strength of material, *(c)* wear resistance of ring and cylinder wall, and *(d)* cost of production. In each of these areas the sintered iron process can contribute to an improved piston ring.

Uniformity of Material – Material uniformity assures consistent engine performance as well as lower-cost ring manufacture. Metal sintering provides uniformity of product because it is a precision operation. It utilizes highly refined raw materials.

Strength Increase – The normal tensile strength of a cast piston ring is about 40,000 psi. Alloy sinterings have 50% higher strength, and experimental material has demonstrated 100% higher strength. (This new material has higher impact and fatigue strength, important in minimizing failures in heavy-duty engines.) The higher strength of sintered rings allows the production of thinner rings without assembly breakage, often experienced with thicker cast iron rings.

Wear Resistance – The third improvement is possible because of the wide range of material combinations available with powder metallurgy techniques. The ease with which hard particles, such as oxides, nitrides and carbides, can be uniformly dispersed offers important new approaches to the solution of wear problems. A piston ring of special sintered iron, installed in a passenger car engine, resulted in wear which was only 10% of the average obtained with gray iron (not chromium plated).

Cost Reduction – Sintering is a precise, closely controlled operation and the product

*Consultant in applied powder metallurgy, New Canaan, Conn.

Table I – Wear on Various Types of Piston Rings*

Type of Ring	Rate of Wear, In. per 1000 Miles			
	Top Compression Ring		Second Compression Ring	
	Radial Face	Axial Side	Radial Face	Axial Side
Typical plain cast iron	0.0020	0.00250	0.00080	0.00060
FM-100 sintered iron	0.0013	0.00025	0.00026	0.00010
Chromium-plated sintered iron (from same engine test as FM-100 ring)	0.0015	0.00030	0.00025	0.00025

*Results of 63,000-mile road test in a V-8 automobile engine.

is free of any skin structure. These features allow production of rings with only a 10% raw materal weight loss, compared to 75% from cupola to finished ring casting. This balances out the difference in cost per pound of raw materials (15¢ versus 4.5¢ for cast iron). The number of basic operations required in producing a finished ring is reduced by one half (see box, right) and many inspection operations required for cast iron rings are eliminated.

Consideration of these improvements caused a major piston ring manufacturer, Muskegon Piston Ring Co., to institute a development program in 1952. Over the years this program has involved 200 different mixes, 30 iron powders, ten graphites, six coppers, three lubricants and ten additives. To remain competitive, the number of processing operations had to be kept to a minimum. Therefore, very close compacting and sintering tolerances had to be maintained. Compacting presses were reworked, special feed shoes were made, and new handling techniques were developed. A special sintering furnace was designed and built to produce sintered rings with a tolerance of 0.005 in. on the O.D., including out-of-round. (Sizing can not be employed because it introduces internal stress which distorts the ring after it is split.)

Basic Operations Required in Producing Automotive Piston Rings

Cast Iron

Make sand mold	Rough grind sides
Cast	Semifinish grind sides
Shake out	Finish grind sides
Strip gates and risers	Mill gap
Clean	Rough bore I.D.
Snag grind	Rough turn O.D.
Rough grind O.D.	Finish turn O.D.
Rough grind I.D.	Finish bore I.D.

Sintered Iron

Compact	Turn O.D.
Sinter	Mill gap
Tumble	Heat shape (shape by heating on a form)
Size	
Side grind (one pass)	

Test Results

More than 100 dynamometer tests and 25 road tests (totaling 600,000 miles) were run on the best material developed, FM-100, which has the following characteristics:

Tensile strength	100,000 psi.
Rockwell hardness	B-95
Density	67 g. per cc.
Modulus of elasticity	18,000,000 psi.
Microstructure	Spheroidized

The result of all of this effort is illustrated by a set of sample rings tested in a passenger car

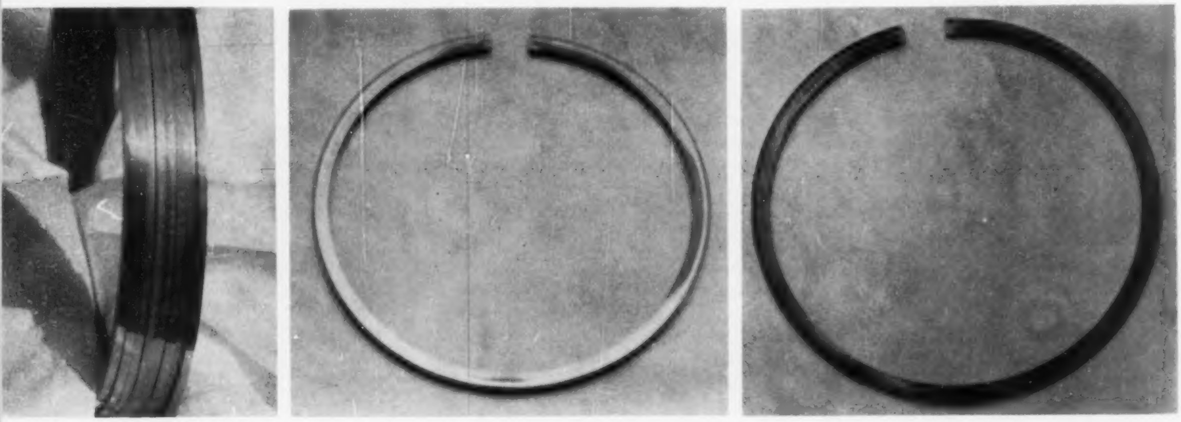


Fig. 1 – (Left) Finish Obtained on O.D. of Piston Rings After 63,000-Mile Road Test in a V-8 Automobile Engine. Shown are compression and second rings from cylinders No. 1 through 4, arranged consecutively from left to right (other half of engine contained chromium-plated rings for comparison). (Center) Finish obtained on side of top (compression) ring from cylinder No. 3. Dark areas are original finish. Average wear was less than 0.0005 in. in 63,000 miles. (Right) Finish obtained on side of a second ring from cylinder No. 3. Note original ground finish scratches on surface. Average wear was 0.0001 in. in 63,000 miles

for over 63,000 miles (Fig. 1). The wear resistance of plain sintered rings was equivalent to chromium-plated rings. Cylinder wear was also reduced – average radial wear was only 0.001 in. on the diameter, and the cylinder surface was extremely smooth (equivalent of a lapped surface). The side wear on the rings was very low, only about 10% of that normally obtained with cast iron (Table I). This factor was responsible for oil mileage being the same at the end of the test as it was at the start (1750 miles per qt.) Because of the smoothness of the cylinder walls, friction was reduced considerably and engine performance was increased.

FM-100* is a low-alloy, high-carbon (1.2%) sintered iron which contains small amounts of copper, manganese and molybdenum. It is made from low-cost reduced iron in one sintering operation. The good wear resistance is due to the alloy content and the uniformly distributed oxides.

*Typical analysis for FM-100: 1.25% total carbon, 0.92% combined carbon, 3.0% Cu, 0.2% Si, 0.005% S, 0.01% P, 0.5% Mn, 0.9% Mo.

Summary

Although the number of hours spent on the successful development of this new piston ring material may seem large, it is only about 0.1% of that spent on the development of cast iron rings. It is difficult to say how much better ring performance and economy would be if the same amount of effort were expended on sintered rings. Because of this experience, and others, we believe that many metal products can be improved in performance and reduced in cost by the application of engineering knowledge concerning sintered products.

Drilling Holes to Measure Residual Stresses

*By ARTHUR J. BUSH**

In this method, a small hole is drilled into the test specimen to relieve the residual stresses. Drilling is stopped at specified intervals, and the changes in stress are determined by strain gages which surround the hole. Brittle lacquer can also be used if a qualitative measurement is desired. (Q25h, G25, ST)

Residual stresses are those stresses which would remain in an elastic solid body if all the external load (forces, couples, and applied stresses), acceleration, and gravitation were removed. Such stresses are produced by some operation, or operations, on the metal, and are commonly classified as macrostresses or microstresses. Macrostresses are those occurring over large areas, while microstresses occur over microscopic particles such as the crystalline grains of a material. Macrostresses, which are made up of an aggregate of microstresses, can be measured by mechanical methods.

Residual stresses may affect materials mechanically or chemically. The most commonly known mechanical effects are the cracking or warping of quenched high-carbon steel parts, castings, or welded structures under static con-

*Engineer, Materials Engineering Dept., Westinghouse Electric Corp., East Pittsburgh, Pa.

Fig. 1 – Steel Test Bar With Mounted Strain Gages and Strain Indicator Were Used to Determine the Sensitivity of the Hole-Drilling Method for Stress Analysis. The bar was ¾ in. thick, and was bent beyond the yield stress to introduce residual stresses before testing

ditions. Also, fatigue life can be drastically reduced by surface stress effects. Another manifestation is a change in dimensions which often occurs during machining when such a stress is relieved.

Measurement Is Difficult

Because of the nature of residual stresses, their measurement has been rather difficult. All mechanical methods of measuring stress, applied or residual, depend on a change in strain as the load is changed. Unfortunately, the only mechanical way to detect strain due to residual stress involves removal of that stress. Since this, in turn, usually implies removal of the stressed material, it ordinarily results in the test specimen being destroyed. In addition, accurate knowledge of residual stress distribution within the part cannot be obtained, even with destruction, on any but the simplest shapes. This occurs because strains cannot be measured at points other than those on exposed surfaces.

For some nondestructive evaluations, x-ray diffraction techniques are useful. However, they are not completely applicable to all materials or to strains in the plastic region. This method measures directly strains in the distorted crystalline lattice of the strained metal.

A procedure which incorporates some of the advantages of both the x-ray and the sectioning mechanical methods is the hole-drilling technique. It can be used on various shapes such as cylinders and plates, as well as on materials where x-ray diffraction is inapplicable.

In the hole-drilling procedure, strain gages are used to measure the strains relieved when a hole is machined into the surface of a structure containing stresses. The method can be used to evaluate both the magnitude and the directions of the principal residual stresses. Stresses can be evaluated to a depth below the surface of about 50% of the hole diameter.

There are some limitations to this method. For instance, the calibration specimen cannot be loaded above a maximum nominal stress of one third of the yield stress. This must be done to prevent plastic deformation; the low value (one third) allows for stress concentrations around the drilled hole. Thus, reliable measurements of stresses are limited to approximately one third the proportional limit of the material. Secondly, a condition of plane stress is assumed: therefore, all stresses are parallel to the surface plane, and finally, the plate must be large with

respect to the diameter of the hole. About ten times as great is recommended.

Procedure Is Simple

In using the hole-drilling method, certain definite procedures are usually followed. A strain-sensing device is attached to the structure to be tested. Resistance-type strain gages are usually used, but Stresscoat (a brittle lacquer) can be employed. A hole is then machined in the structure, and the strain pattern is plotted and studied to analyze stress in the material. When using strain gages, a definite pattern for their placement is employed, depending on the types of stress present.

The hole can be machined by any method such as spark machining, milling, or drilling. In tests on steel, with resistance-type strain gages, holes of various sizes have been used by different investigators. For example, a 6-mm. diameter hole was used in one test. In another series, hole sizes of 1/4 to 1/2 in. were used. The 1/4-in. diameter hole was found to give the best results. When using brittle lacquer, a hole size no larger than 1/8 in. is recommended.

Machining a ring around strain gages to relax the strains present is a variation of the hole-drilling procedure which is claimed by some to be more sensitive. As yet, not much literature is available on this method, and in preliminary tests the results did not compare favorably with those from hole drilling.

To use the strain values obtained from the gages, calibration constants are necessary. Such constants are determined on a previous test piece, and are a function of the depth of the hole and the thickness of the plate. In addition to being restricted to the hole diameter, gage types and their arrangements, and specific machining procedures, these constants are applicable only to the same alloy used for the calibration test piece.

To evaluate the sensitivity of the hole-drilling technique when applied to steel, our laboratory tested a specimen of cold rolled steel. For this test, a steel bar, 4½ by ¾ by 20 5/16 in., was loaded to introduce residual stresses. This was done by bending (until several layers of fibers were stressed beyond the elastic limit) and relieving the load. Naturally, residual stresses remained.

Before milling the hole to relax stresses, a small guide hole was required. Therefore, a 5/64-in. hole was first drilled, and four A-7 SR-4 wire strain gages positioned around it as shown in Fig. 1.

The specimen was placed in the milling machine, and clamped in position. Gage readings were taken to determine the effect of clamping; this effect was found to be negligible. A 1/4-in. diameter end mill was used with a 1/8-in. per min. vertical feed and a speed of 1160 rpm. (In preliminary tests, this feed and speed were found to give a good cut with very little heating of the specimen.) A reading was taken 5 min. after every cut of 0.020-in. depth, the waiting period being needed for conditions to stabilize.

The resulting curve (Fig. 2) indicates that this drilling method is quite sensitive, and has good possibilities for measuring stress as a function of depth. However, if actual stress values are needed, calibration tests on a specimen containing stresses of a known magnitude must be performed.

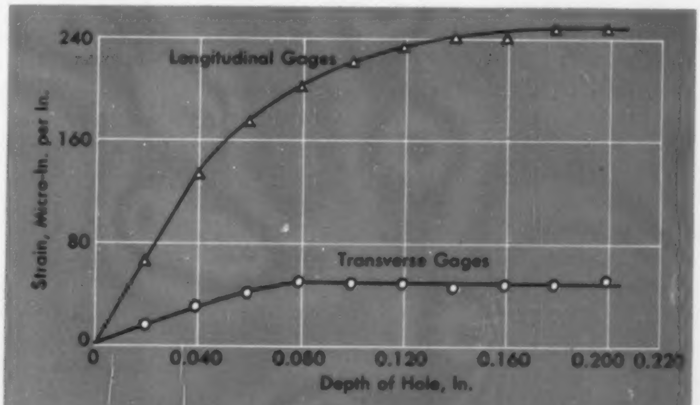


Fig. 2 — Strains Relieved by Milling 1/4-In. Diameter Hole in Test Bar Shown in Fig. 1

Phase Identification in Nickel-Base Alloys

By J. E. WILSON
*and J. F. RADAVICH**

As-cast structures contain gamma prime, Ni_3Al, a complex boride, and titanium carbonitride. During heat treatment the carbonitride breaks down and another complex carbide forms at its expense. Grain size and distribution of phases determine rupture life. (M27, M21e, M22g; Ni-b, SGA-h)

In recent years, a good deal of research effort has been expended on the development of nickel-base alloys. Aimed principally at finding improved alloys for jet turbine blades, the work has been rewarded with the birth of such alloys as Nicrotung, Inco 713C, DCM, Astroloy, Cosmoloy and René 41.

Important in any alloy research is the job of identification of phases. This report concerns such a study of DCM alloy, the base for Cosmoloy and Astroloy development. Much of the information presented here, however, applies as well to other cast and wrought nickel-base alloys containing aluminum, titanium, molybdenum, chromium and boron.

DCM was developed by G.E.'s Jet Engine Dept. in 1957 as a turbine bucket alloy for service up to 1800° F. Principal alloying elements are chromium (14 to 16%), titanium (3.35 to 3.65%), aluminum (4.4 to 4.8%), molybdenum (4.5 to 6.0%), iron (4.0 to 6.0%) and boron (0.070 to 0.090%). Nickel makes up the balance. As reported earlier (*Metal Progress*, November 1958, p. 83), initial heats showed excellent stress rupture life at 1800° F. and 15,000 psi. – far better, at that time, than any available commercial alloy.

The matrix in DCM is a nickel-base solid solution. Extensive studies of microstructures indicate that, besides gamma prime phase, Ni_3Al, a complex boride, M_3B_2, and a titanium carbonitride phase, Ti(C,N), are present in the as-cast alloy. All of these phases are found at the grain boundaries; however, gamma prime is most prevalent in the matrix, the others in the boundary regions. Boride and carbides are those of chromium, but the other alloying elements are also involved.

Upon heat treatment or testing at elevated temperature, another carbide phase, $M_{23}C_6$, forms at the expense of the carbonitride. Significantly, fine-grained DCM alloy, which has substantially shorter rupture life than the coarse-grained material, also contains more $M_{23}C_6$. Short rupture life probably results from microcracks which initiate in fine-grained metal at regions where $M_{23}C_6$ or agglomerated gamma prime phase are concentrated in the grain boundaries. Fine-grained DCM alloy is also less resistant to intergranular oxidation.

Phase studies were made of samples of different grain size from four test bars used in rupture tests and from three vacuum induction cast DCM ingots in the as-cast or heat treated condition. Grain size and rupture life are given in Table I.

Precipitates at Grain Boundaries

When viewed under the optical microscope, the three as-cast and heat treated ingot samples revealed extensive precipitation at grain boundaries. In fine-grained metal, however, agglomeration of M_3B_2 was less pronounced.

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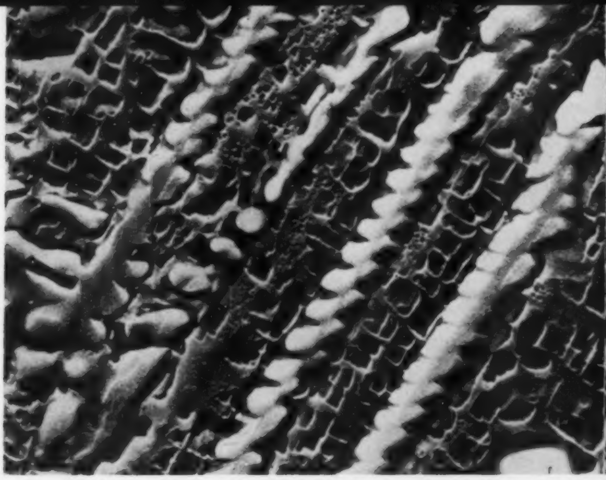


Fig. 1 — Boride Phase (M_3B_2) at Grain Boundaries of As-Cast DCM Alloy. Matrix is Ni_3Al. 14,000 ×

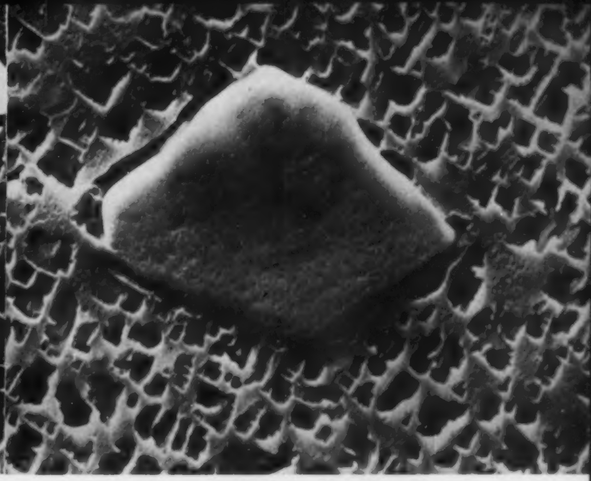


Fig. 2 — Particle of Titanium Carbonitride Surrounded by Ni_3Al in As-Cast DCM Alloy. 14,000 ×

Fig. 3 — Titanium Carbonitride Breaks Down, as Shown Here, to Complex Carbide ($M_{23}C_6$) During Exposure to High Temperature. Specimen was given standard heat treatment (see Table I), then held at 1800° F. for 100 hr. 14,000 ×

Fig. 4 — Structure of Fine-Grained DCM Ingot (Sample No. 3, Table I) Which Was Given Standard Heat Treatment. Extensive $M_{23}C_6$ particles at grain boundaries are one cause of short rupture life. 14,000 ×

Fig. 5 — Electron Micrograph of Fine-Grained Rupture Bar (Sample No. 5, Table I) Showing $M_{23}C_6$ or M_3B_2 (or Both) Particles at a Grain Boundary and Dispersed Throughout the Matrix. 14,000 ×

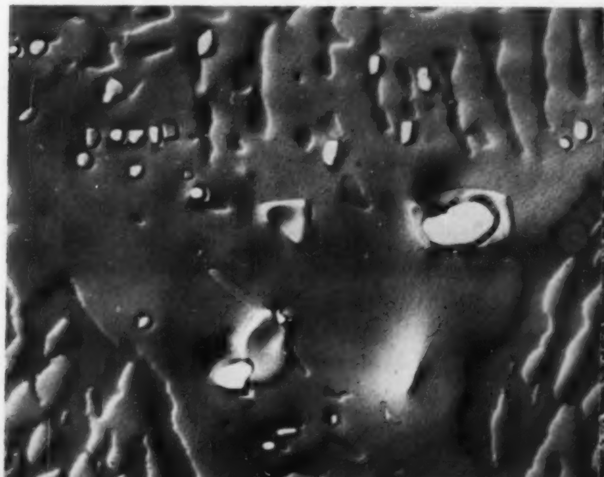
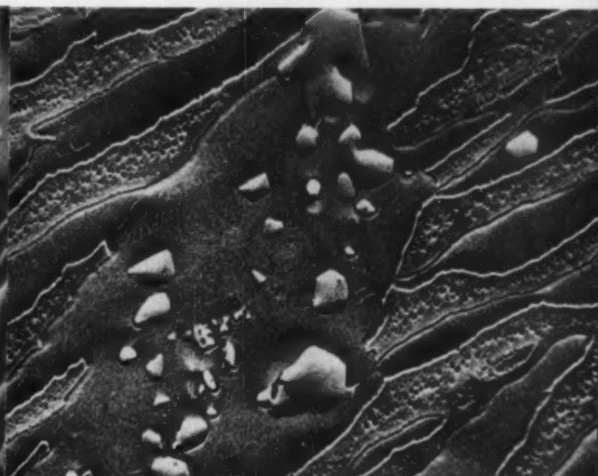


Fig. 6 — Carbide and Boride Particles in Large-Grained DCM Specimens of Long Rupture Life Are Limited, for Most Part, to Grain Boundaries. Specimen is from sample No. 4 (Table I). 14,000 ×



Under the electron microscope, largest particles at the grain boundaries actually proved to be smaller particles which had agglomerated (Fig. 1). This structure is the double boride, M_3B_2. Titanium carbonitride, as shown in Fig. 2, is more spheroidal in shape than M_3B_2 and after etching it stands in greater relief. In specimens held for 100 hr. at 1800° F. following the standard heat treatment, $M_{23}C_6$ forms at the expense of titanium carbonitride (Fig. 3). Although the greatest amount of $M_{23}C_6$ is found at grain boundaries (Fig. 4), it apparently also occurs within the grains.

The electron microscope also revealed that in fine-grained samples taken along the longitudinal axis of rupture bars there is a large amount of gamma prime at the grain boundaries and, as shown in Fig. 5, a fine precipitate of $M_{23}C_6$ or M_3B_2 (or both), Ni_3Al and Ti (C,N) dispersed throughout the structure. In the bar with coarsest grains (No. 4 in Table I), carbide particles were larger and for the most part they were concentrated at grain boundaries (Fig. 6). This bar also revealed a subgrain structure in large agglomerates of gamma prime indicating growth of that phase within primary grain boundaries.

More Residue in Fine-Grained Metal

For x-ray diffraction work, the samples were electrolytically digested (15 v., 1½ amp.) in a solution of 10% HCl in methanol. In this phase-isolation technique, gamma prime does not settle out as a residue. Minor phases are thus more readily concentrated. The amount of residue isolated from the ingot samples increased as the grain size increased. About twice as much residue was isolated from each of the fine-grained rupture samples as from the large-grained bars.

X-ray diffraction studies of the residue confirm the previous observation that the principal phases other than Ni_3Al in as-cast ingots are M_3B_2 and Ti(C,N). The complex $M_{23}C_6$ forms during heat treatment and during rupture testing at 1800° F. Simultaneously, the amount of Ti (C,N) diminishes. Examination of residue by x-ray fluorescence technique indicates that the precipitating phase, $M_{23}C_6$, contains a considerable quantity of chromium.

In the rupture bars which were stressed while at 1800° F., the main phases are M_3B_2 and $M_{23}C_6$. Some titanium carbonitride is present but to a greater extent in large-grained samples than those of fine grains. Weak lines which correspond to Fe_2Ti, Fe_2B or Ni_2B were also detected in the fine-grained metal.

Table I – Grain Size and Rupture Life of DCM Alloy Specimens

Sample	Type	Macro Grain Size	Rupture Life*
1	Ingot	1/8 to 3/16 in.	400-500 hr.
1(*a*)	Ingot	1/8 to 3/16	—
1(*b*)	Ingot	1/8 to 3/16	—
2	Ingot	1/64 to 1/16	273
2(*a*)	Ingot	1/64 to 1/16	—
2(*b*)	Ingot	1/64 to 1/16	—
3	Ingot	Less than 1/64	55.9
4	Test bar	3/16	400
5	Test bar	Less than 1/64	83.7
6	Test bar	Less than 1/64	52.4
7	Test bar	Less than 1/64	75.7

*At 1800°F., 15,000 psi. Only those specimens given standard heat treatment were rupture tested.

(*a*) As cast.

(*b*) Given standard heat treatment (1 hr. at 2100° F., air cool; 2 hr. at 1950° F. air cool; 4 hr. at 1550° F., air cool) and held at 1800° F. for 100 hr.

Studies were made of cross-sectioned bars to determine phase distribution near the outer surfaces of specimens which had been heat treated and rupture tested. Regardless of grain size, the structure changes from that of the base metal to a depleted zone of Ni_3Al, a layer of alpha Al_2O_3, and on the surface, scales of $(Cr, Fe)_2O_3$ and spinel oxide. The presence of the alpha Al_2O_3 layer is to be expected in view of the zone of depleted Ni_3Al. Little is known of the effect of the alpha Al_2O_3 on resistance to high-temperature oxidation in this alloy system.

Iron Diffusion

Chemical analysis of the oxide scales shows that they have a high percentage of iron compared to that of the base metal. During digestion of fine-grained samples, oxide flakes of high iron content were also isolated from the regions of microcracking. Diffusion of iron to the grain boundaries and to the surface is apparently more rapid in fine-grained than in large-grained DCM alloy. Observations made on the regions of microcracks at grain boundaries show large concentrations of $M_{23}C_6$ and Ni_3Al as well as oxide particles. The amount and propagation of the cracks must then be related to the concentration of the carbide phase, agglomerated Ni_3Al, and formation of an iron-rich oxide.

Circle 1909 on Page 48-B

Machining AM350, Solution Treated and Aged to Bhn. 444

Operation	Tool Material	Tool Geometry (*a*)	Tool Used for Tests	Depth of Cut	Width of Cut	Feed	Cutting Speed	Tool Life	Wear-Land (*b*)	Cutting Fluid
Turning	C-2 carbide	SR: 5°; SCEA: 15°; BR: 0°; ECEA: 15°; Relief: 5°	½-in. square throwaway holder with mechanical chip breaker	0.100 in.	—	0.009 in./rev.	150 ft./min.	40+ min.	(*c*)	None
Turning	Stellite 98 M-2 cast alloy	SR: 15°; SCEA: 0°; BR: 0°; ECEA: 5°; Relief: 5°	⅝-in. square tool bit	0.060	—	0.009 in./rev.	70	80 min.	0.060 in.	Soluble oil (20:1)
Turning	T-15 HSS	SR: 15°; SCEA: 0°; BR: 0°; ECEA: 5°; Relief	⅝-in. square tool bit	0.060	—	0.009 in./rev.	40	75 min.	0.060	Soluble oil (20:1)
Face milling	C-2 carbide	AR: 0°; ECEA: 5°; RR: 0°; Cl: 8°; CA: 45°	5-in. diam., 5-tooth, inserted-tooth face mill	0.100	2 in.	0.005 in./tooth	120	37 in./tooth	0.012	None
Face milling	T-15 HSS	AR: 0°; ECEA: 5°; RR: 0°; Cl: 8°; CA: 45°	4-in. diam., single-tooth face mill	0.060	2	0.010 in./tooth	60	70 in./tooth	0.030 localized wear	Soluble oil (20:1)
Side milling Down milling setup	C-2 carbide	AR: 0°; ECEA: 5°; RR: −15°; Cl: 8°; CA: 45°	7-in. diam., 6-tooth, inserted-tooth face mill	0.100	1¾	0.010 in./tooth	120	50 in./tooth	0.016	None
Slot milling Down milling setup	C-1 or C-2 carbide	AR: 5° bi-negative; RR: −5°; ECEA: 1°; CA: 45° × 0.030 in.; Cl: 8°	6-in. diam., brazed 6-tooth slotting cutter	0.250	1	0.003 in./tooth	125	63 in./tooth	0.016	None
End milling	T-15 HSS	35° RH helix; CA: 45° × 0.060 in.; Per. Cl: 15°	¾-in. diam., 4-flute end mill (*d*)	0.250	¾	0.002 in./tooth	70	150 in.	0.008	Soluble oil (20:1)
Drilling	T-15 HSS	2-flute, 118° crankshaft point; 7° clearance	¼-in. diam. drill, 2½ in. long (*e*)	0.500 through hole	—	0.005 in./rev.	20	107 holes	0.016	Highly sulphurized oil + light machine oil (1:1)
Tapping	M-10 HSS	4-flute taper tap; 75% thread	5/16-18 NC taper tap	0.500 through hole	—	—	5	200+ holes	(*f*)	Highly chlorinated oil

(*a*) AR = axial rake; RR = radial rake; CA = corner angle; SR = side rake; BR = back rake; SCEA = side-cutting edge angle; ECEA = end-cutting edge angle; Cl = clearance.
(*b*) Wear on the peripheral flank of the cutter.
(*c*) Test stopped at 40 min. tool life, 0.005 in. wear-land.
(*d*) For end mills ½-in. diam. and over. Flute length should be short as possible for maximum rigidity.
(*e*) Use stub length drills whenever possible.
(*f*) Test discontinued; tap still cutting.

Source: Metcut Research Associates

The Electron Microscope . . . a New Tool for Examining Fractures

By AUSTIN PHILLIPS
*and GUY V. BENNETT**

Fracture surfaces of metals can now be examined at magnifications up to 50,000 × by the electron microscope. This technique, termed "electron microfractography", may become an important tool in failure analysis; it promises to reveal many of the heretofore undisclosed details associated with the various failure phenomena. (M12e, M23p)

THE STUDY OF METAL FRACTURES by visual observation and by the light microscope is perhaps one of the oldest techniques known to metallurgists. Because of the efforts of investigators such as C. A. Zapffe, this type of examination has become continually more valuable through the years. As a result, the metallurgist of today can identify and interpret much more accurately the various causes of metal failure.

It is significant, however, that this improved insight into fracture mechanisms has come with the improvement in design and manufacture of microscopes. The wave length of visible light imposes a physical limitation on resolution and as a result an impasse has been reached in recent years. At top magnification, the light microscope is seriously limited as to resolution and depth of focus for examining fracture surfaces.

Fortunately we can turn to a new tool, the electron microscope. Because it can provide a greater depth of focus and a higher resolution (far exceeding that of any optical microscope), this device is well suited for the examination of fracture surfaces. Furthermore, the gain in magnification is immense – the top magnification for the light microscope is 2000 ×, while an electron microscope can go up to 200,000 ×.

Surface Replicas Needed

There is one drawback, however. A metal specimen of any appreciable thickness cannot be examined directly under the electron microscope in the way one employs the light microscope. Light waves are reflected, but electrons penetrate the specimen in much the same way as x-rays pass through a metal during radiographic inspection. Thus, thin replicas of the surface must be produced. It is this replica which is examined in the electron microscope.

At Douglas, techniques have been devised (and are continually being improved) for obtaining replicas from fracture surfaces, a difficult task since they are usually quite rough. (A polished surface is normally employed in electron-

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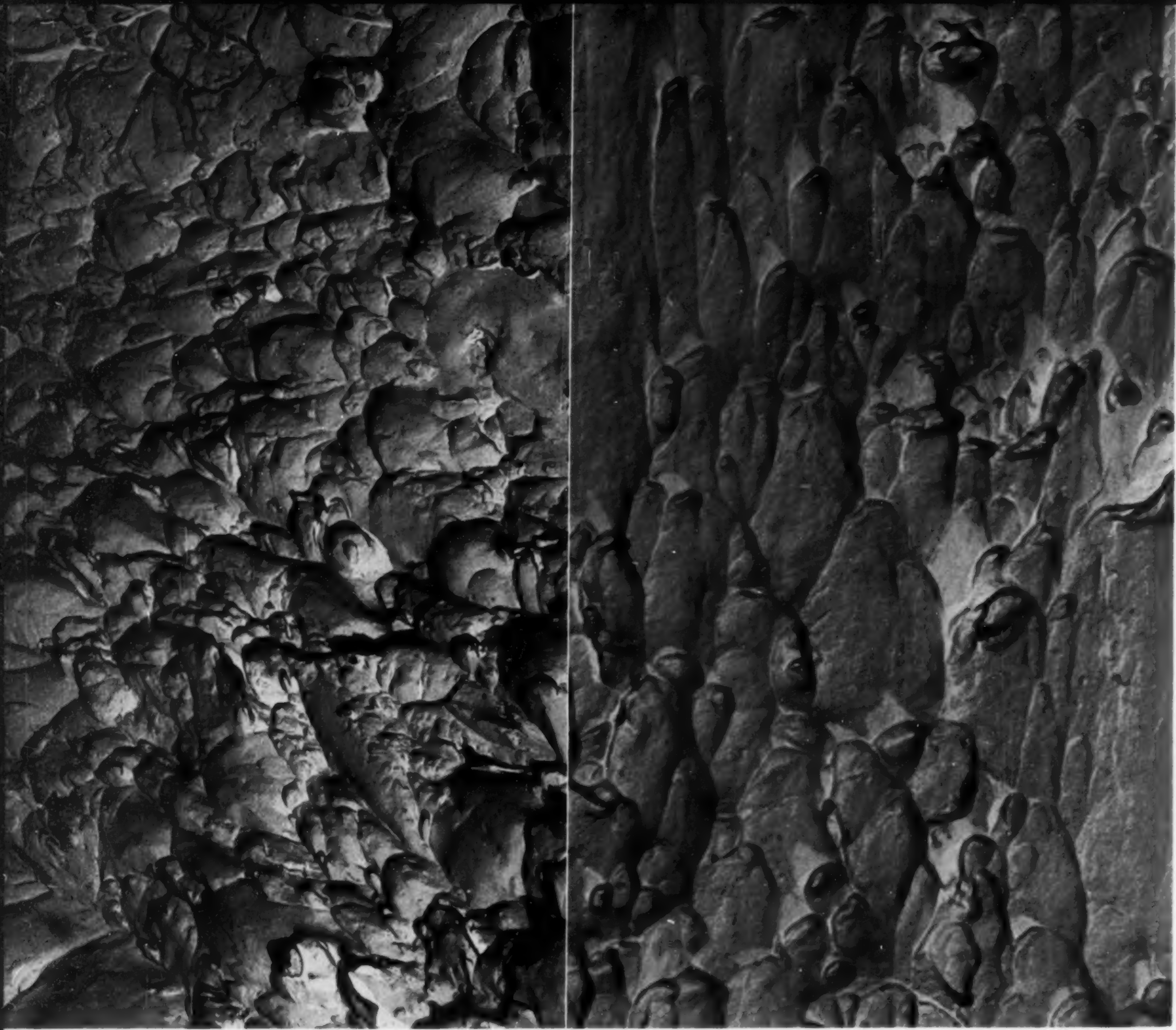


microscope studies of microstructure.) When a successful technique for replication* had been devised, engineers began to study fractures produced by various failure mechanisms. After learning the characteristic topography of fractures produced by known mechanisms, they then applied the technique to determine the cause of failures when other methods were inconclusive. Some of the interesting observations made in these studies form the basis of this article.

*To prepare the replica, a thin sheet of cellulose acetate (softened in acetone) is applied to the fracture, forming a plastic negative. When this negative is dry, it is stripped from the surface and shadowed with chromium vapor (in vacuum) 45° to the replica plane. Next, carbon is deposited normal to the replica face.

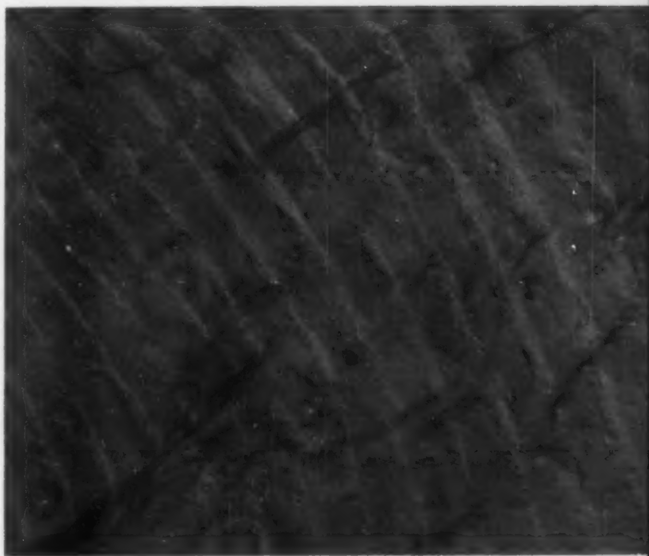
The replica specimen is then cut into small squares, and the plastic negative subsequently dissolved away in acetone. This leaves square sections of a preshadowed positive replica of carbon floating in the acetone bath. After these sections are strained from the liquid on a 200-mesh copper screen and washed in vapors of acetone for several hours, they are ready to be examined.

Studies of Various Fractures

Ductile fractures have some unusual features as the fractographs in Fig. 1 illustrate. The one on the left represents the center portion of a cup-and-cone fracture of a tensile specimen of A.I.S.I. 4340 steel quenched and tempered to a tensile strength of 260,000 psi. The surface is divided into many small areas, each of which somewhat resembles a teardrop. These areas, which have been termed domains, are characteristic of fracture surfaces in which much plastic flow occurred before rupture. Figure 1, right, shows a fractograph of a surface of a shear specimen of the same steel. In this instance, the domains are extensively elongated in the direction of the shearing force, rather than being randomly oriented as in the tensile specimen. This observation can sometimes be

Fig. 1 – Tensile and Shear Fractures in Test Bars of A.I.S.I. 4340 Heat Treated to 260,000 Psi. The many small areas into which the surfaces are divided are called domains; they characterize fracture surfaces which have undergone much plastic flow. In the shear specimen (right) the domains are elongated. This characteristic can sometimes be used to determine the direction of force. Left, 13,700 ×; right, 27,000 ×

Fig. 2 – A Typical Fatigue Failure at Three Different Magnifications. At 250 × (center), additional rings (or "beach marks") can be found between those which are visible to the naked eye (top, 1½ ×). When this fracture surface is then examined through the electron microscope (at 7000 ×), other rings, called arrest lines, can be noted between the beach marks



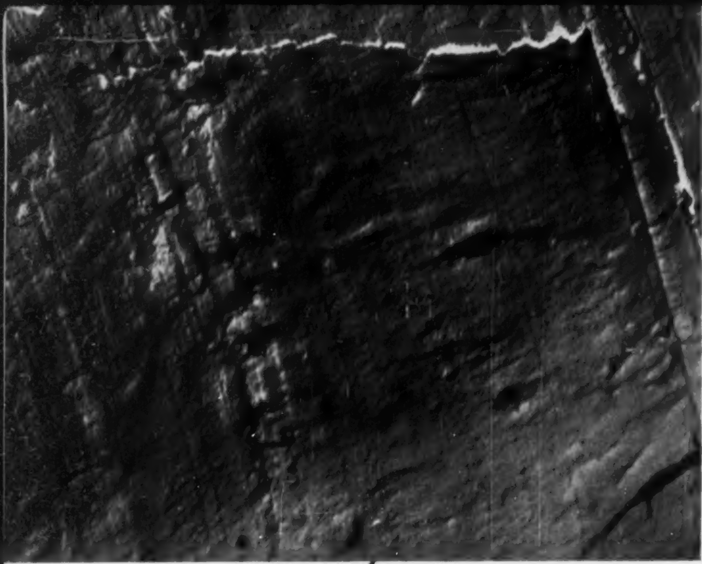
useful in determining the direction of fracture.

Fatigue fractures also have distinguishing characteristics. Three views of a typical fatigue failure which occurred in 7075-T 6 aluminum alloy are shown in Fig. 2. One need only look at the fracture at low magnification to see that the part failed in fatigue. However, when the fracture is examined with the light microscope, at 250 ×, for example, additional rings or "beach marks" are observed between those visible at the lower magnification. Going one step further, when this fracture is examined at 7000 × under the electron microscope, smaller rings or arrest lines can be seen between those which are visible at 250 ×. The spacing between these arrest lines increases with the distance from the origin of failure.

Hydrogen Embrittlement

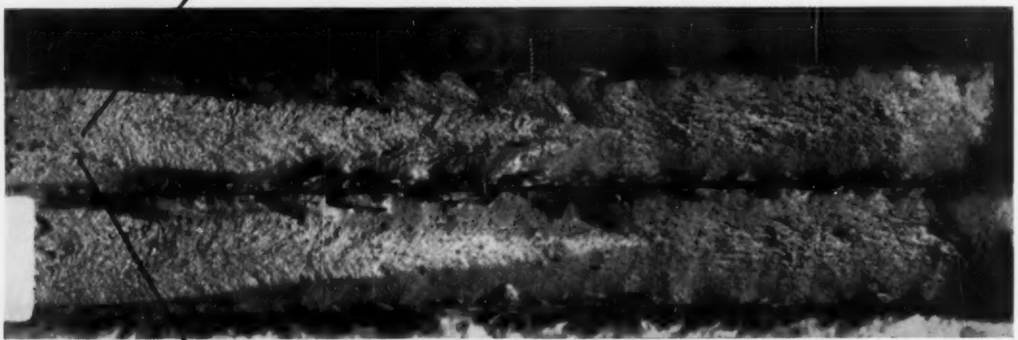
In high-strength steels (above 200,000 psi.) hydrogen often introduces a type of failure which goes by several names; static fatigue, delayed cracking, and delayed failure are three of them. Whatever the name, the fractures produced by this mechanism have been studied extensively under the electron microscope.

Figure 3 shows some of the interesting features observed on the fracture of a notched specimen of A.I.S.I. 4340 that had been cathodically charged with hydrogen before being statically loaded. Failure occurred in 27 hr. As the fracture surfaces (at 10 ×) show, the crack began at the left side of the specimen and propagated toward the right. Where the crack formed and grew slowly, the fracture contains



two distinguishing features: hydro-indication sites and propagation lines. The existence of the latter feature suggests that this type of fracture is discontinuous, at least at those portions of the fracture where they appear. However, only a small portion of the surface in the area of slow growth contained these propagation lines; the remainder contained hydrogen-indication sites. At 27,000 ×, these sites appear as voids at what are believed to be subgrain boundaries in the steel.

When there is only a small amount of



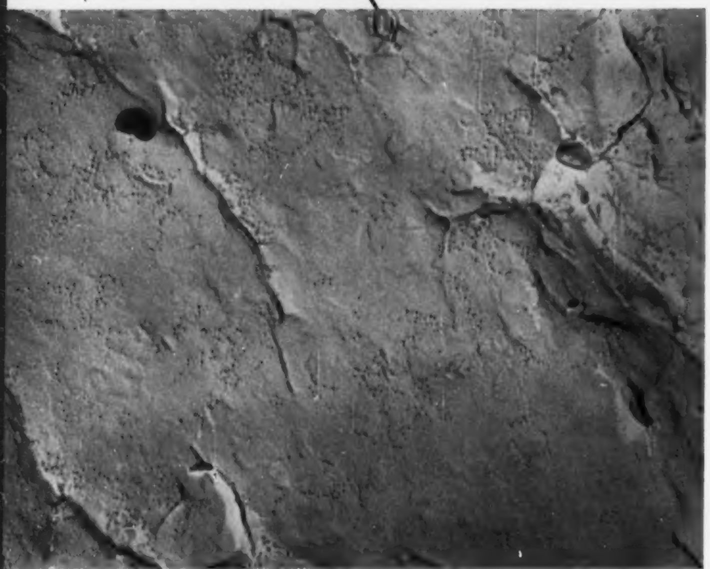


Fig. 3 — Delayed Failure in Hydrogen-Embrittled A.I.S.I. 4340. The fracture reveals hydrogen-indication sites (bottom) which appear to be voids at subgrain boundaries. The propagation lines (top) indicate that fracture growth is discontinuous in certain areas. Fracture surface, 10 ×; micrographs, 27,000 ×

hydrogen present at the time the same steel (A.I.S.I. 4340) is under static stress, the fracture surface appears quite different, as Fig. 4 shows. In this instance, the specimen received hydrogen while being cadmium plated by a low-hydrogen process. After plating, it was baked for 23 hr. at 395° F. Then, while a static stress of 170,000 psi. was applied, the specimen was intermittently immersed in tap water until it failed. In this instance, the fracture surface was highly faceted, appearing much like rock candy. Obviously, the appearance of the fracture produced by hydrogen embrittlement is affected by the amount of hydrogen present as well as the magnitude of the static stress.

Applying the Technique

This technique is not merely a laboratory curiosity. When used for analyzing several failures, it has provided us with conclusive identification of the mechanism causing them. For example, Fig. 5 shows the fracture surface of a portion of a struc-

Fig. 4 — Delayed Failure in a Ring Embrittled by Hydrogen During Cadmium Plating. Apparently, the smaller amount of hydrogen in this specimen (compared to that in the test bar illustrated in Fig. 3) produces a different mode of fracture. In this instance, the rock-candy surface indicates intergranular failure. 5700 ×

ture that had been fatigue tested under simulated service conditions. Although loading was cyclic and fatigue failure should occur, the fracture contained none of the characteristic marks common to fatigue. (This was undoubtedly due to the high-stress, low-cycle nature of the test.) However, examination under the electron microscope proved that it was indeed a fatigue failure; the multiple origins of failure all contained arrest lines as shown in the figure.

Another example is shown in Fig. 6; in this instance the part (A.I.S.I. 4340 heat treated to 260,000 to 280,000 psi.) failed in service. As can be seen, failure began at the "moon" shown at the top of the fracture face. However, examination of this zone at 50 × did not reveal any evidence of fatigue or features characteristic of other failure mechanisms. When the

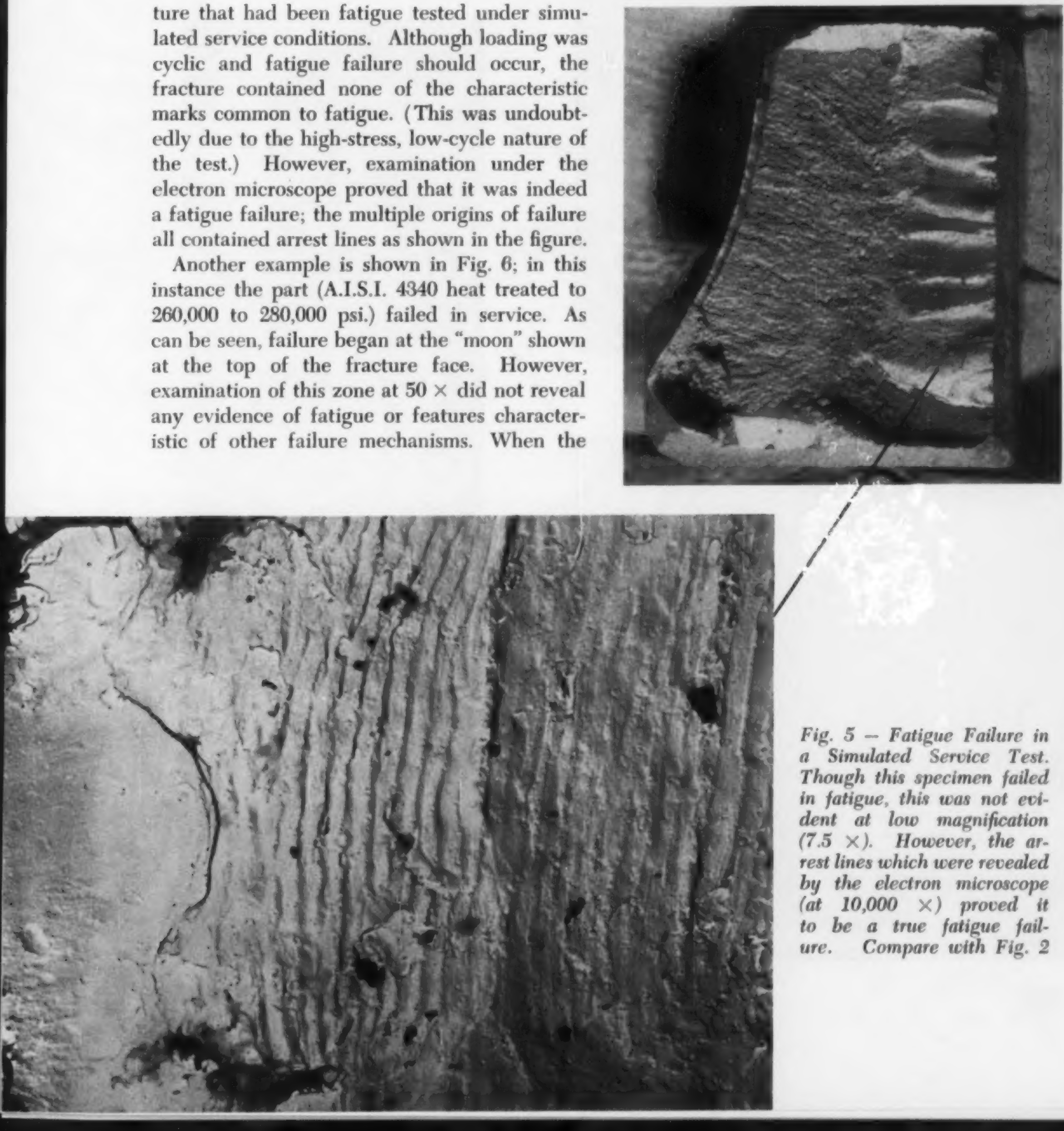
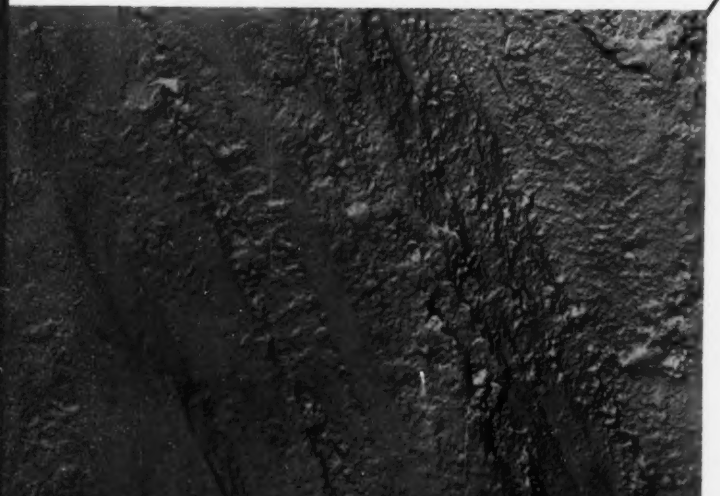


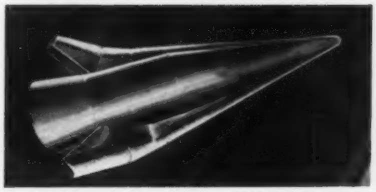
Fig. 5 — Fatigue Failure in a Simulated Service Test. Though this specimen failed in fatigue, this was not evident at low magnification (7.5 ×). However, the arrest lines which were revealed by the electron microscope (at 10,000 ×) proved it to be a true fatigue failure. Compare with Fig. 2

fracture surface was examined under the electron microscope, the cause of failure became apparent. The apex of the moon, the point of crack initiation, had the rock-candy surface characteristics of delayed failure, and the remainder of the moon possessed arrest lines. From this investigation it was obvious that hydrogen embrittlement was responsible for the failure. Once the crack formed, it propagated by fatigue to the point where rupture occurred.

In conclusion, electron-microscope studies of fractures produced by various failure mechanisms has enhanced the knowledge of deformation and fracture modes. "Electron microfractography" has become an important tool in failure analysis, and promises to reveal many of the undisclosed details associated with the various failure phenomena.

Fig. 6 — Fracture Surface of a Part Which Failed in Service. Using the electron microscope, an intergranular surface characteristic of delayed failure (see Fig. 4) was revealed at the apex of the "moon" at which failure began; remainder of moon was formed by fatigue. Fracture surface, 2.5 ×; intergranular fracture, 4000 ×; arrest lines, 12,000 ×





Fabrication Studies on Columbium Alloy Sheet

*By ANDREW F. TRABOLD and STEVEN BANK**

Preliminary tests indicate that D-31 sheet (10% Mo, 10% Ti) has relatively good formability; its machining characteristics are similar to austenitic stainless steel. The alloy has fair bendability, but its weldability leaves much to be desired. The material can be sheared cold; it can be dimpled at 500° F. but not at room temperature. (G-general, G17k, K9s, Q23q; Cb-b, 4-53)

A NEW COLUMBIUM-BASE ALLOY, D-31†, is being considered as a material for re-entry space vehicles. It has moderate high-temperature strength, compared to other columbium-base alloys, and possesses relatively good resistance to high-temperature oxidation and oxide contamination. Mechanical properties of D-31 sheet (cold rolled and stress relieved) at various temperatures are:

TEMPERATURE	TENSILE STRENGTH
Room*	113,000 psi.
1200° F.	68,000
1600	55,000
2000	30,000
2400	10,000

*6 to 9% elongation.

The leading edges of space vehicles under consideration at Grumman will probably be of the "built-up" corrugated type. To accumulate manufacturing data needed for fabricating a leading edge from D-31 sheet, we investigated the welding, dimpling, shearing, machining, bending and forming characteristics of the alloy. Because the supply of sheet was limited, results obtained are only indicative of its fabricability and should not be considered as final. Tests were made on cold rolled sheet that was stress relieved only; complete recrystallization (1 hr. at 2400° F.) destroys ductility.

Weldability Studies

The major deterrent to successful welding is an embrittling precipitate which forms in the heat-affected zone. To prevent this, we considered joining techniques – spot welding and electron beam welding – which minimize the heat-affected zone.

In the spot-welding evaluation, a short-time,

*Group Leader and Metallurgist, respectively, Manufacturing Metallurgy Group, Grumman Aircraft Engineering Corp., Bethpage, L.I., N.Y.

†Du Pont's trademark for a columbium alloy containing 10% Mo and 10% Ti.

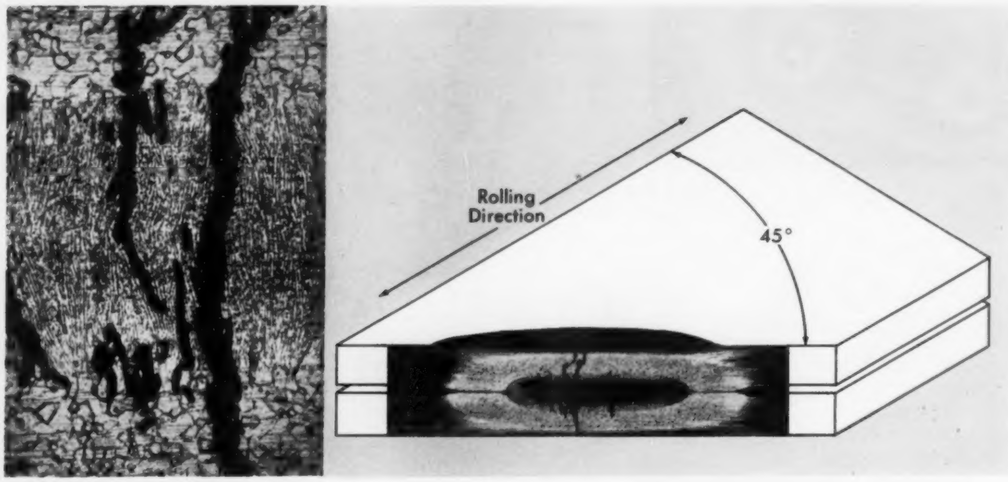


Fig. 1 – Micrograph of Typical Spot Weld in D-31 Sheets. The cracks are at 45° to the direction of rolling. 40 × (left) and 8 × (right)

low-heat cycle was used. X-ray analysis and metallographic examination of welded samples revealed cracks extending through the material and running 45° to the rolling direction. A micrograph of a spot weld (Fig. 1) shows excessive electrode indentation and sheet separation and an undersize weld nugget. Surrounding the as-cast nugget structure is a zone of partially recrystallized material which is very brittle. Du Pont reports that it is possible to produce ductile, crack-free spot welds by keeping the weld cycle time as short as possible.

Electron beam welding differs from ordinary fusion welding in that energy concentrations are exceedingly high, the weld cycle is completed in a short time, minimizing heat-affected areas, and welding is done in a vacuum chamber, eliminating atmospheric contamination.

Hamilton Standard Corp. welded two small samples of D-31 on a Carl Zeiss 150-kv. electron beam welder. The machine was set at 100 kv., 2.5 milli-amp., with a feed of 30 in. per min. Figure 2 illustrates the surface of the weld. A microsection (Fig. 3) shows recrystallization, incomplete penetration, undercutting, and porosity in the weld. Tensile and bend tests revealed the weld to be extremely brittle and low in strength. Failure occurred through the welded section which had numerous cracks.

Dimpling Tests

In missile and aircraft construction, thin fairing surfaces (skins) are connected to support members by rivets. It is important that the rivet heads be flush with the skin surface to minimize turbulence. Since skins are thin-gage sheet, countersinking is not possible; re-

Fig. 2 – Macrograph of D-31 Sheets Joined by Electron Beam Welding. 20 ×

Table I – Chemical Composition of D-31 Sheet

Element	As-Received Sheet	Specification	
		Nominal	Range
Carbon	0.0035%	0.006%	0.01% max.
Oxygen	0.0773	0.05	0.04 to 0.10
Nitrogen	0.0102	0.007	0.015 max.
Hydrogen	0.0010	0.0002	0.0005 max.
Titanium	7.81	10.0	9.0 to 11.0
Molybdenum	10.54	10.0	9.0 to 11.0

cessions or dimples must be made instead.

Dimpling tests were performed at room temperature, and at elevated temperature (500 to 625° F.) using a hot pressure pad. All dimples produced at elevated temperatures were satisfactory and showed no evidence of cracking by x-ray and metallographic examination. All dimples produced at room temperature exhibited cracks running 45° to the rolling direction, similar to those on the spot-welded samples.

Any attempt to explain this apparent plane of weakness must assume that the behavior of columbium alloys is similar to that of other body-centered cubic materials when rolled. The crystal orientation in D-31 sheet after rolling would be one in which the (001) planes would lie essentially in the plane of the rolled sheet, with the (110) directions of the grains lying in the direction of rolling. This orientation places the cube faces (100) at 45° to the rolling direction. Fracture of this material might then occur on cleavage planes – planes with low indices, the {100} family – if the alloy is sensitive to cleavage failure.

According to Du Pont, 45° brittleness may be minimized by using sheet with an interstitial content below 550 ppm. and nitrogen below 80 ppm. (Table I shows the interstitial content of the sheet for this evaluation was 920 ppm. and the nitrogen content was 102 ppm.) and by keeping interstitial contamination low by preventing oxygen, nitrogen and hydrogen from diffusing into the sheet during high-temperature treatments. In D-31 sheets with high interstitial content, dimples can be successfully produced by increasing the forming temperature to 500 to 625° F.

Shearing Characteristics

We sheared the first specimen with a blade gap setting of 0.002 in., commonly used in cutting stainless sheet. Die penetrant inspection indicated the presence of "cracks" on the sheared edge. Metallographic examination revealed these indications to be an unusual serrated edge on the sheared surface as shown in Fig. 4.

Although D-31 sheet can be sheared successfully at room temperature using a 0.002-in. gap setting, better edges may be obtained with other settings. However, if material is sheared as described above, we recommend deburring

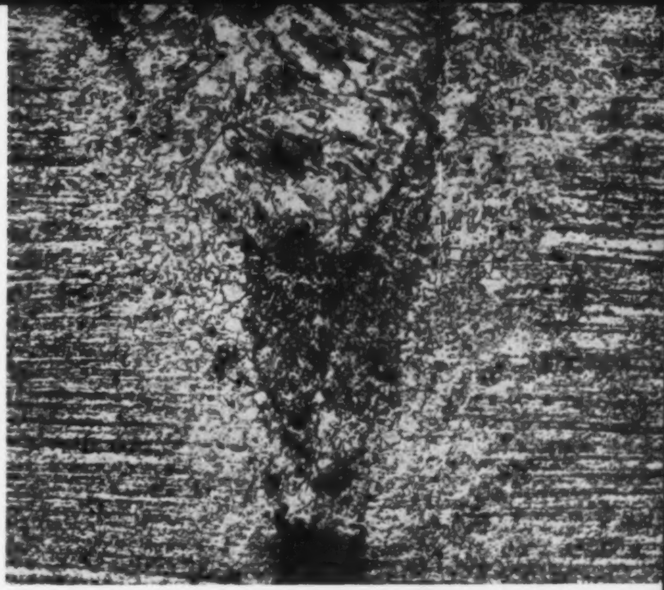


Fig. 3 – Micrograph of Fusion Zone Shown in Fig. 2. Note recrystallization, incomplete penetration, undercutting and porosity. Depth-to-width ratio is 1.75 to 1. 100 ×

Fig. 4 – Sheared D-31 Sheet Showing Serrated Edge. No shear cracks are visible. 170 ×

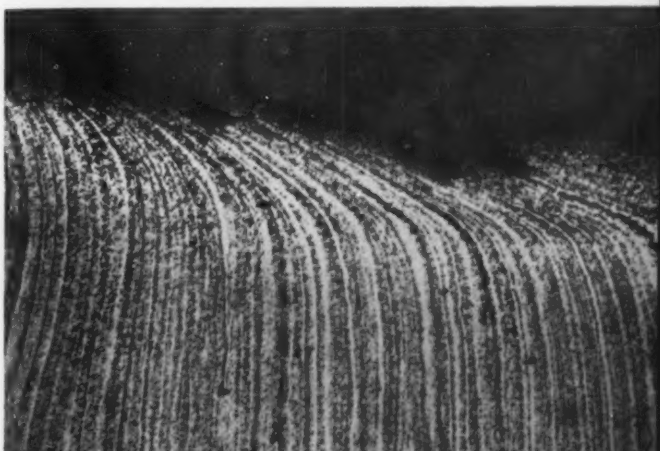


Fig. 5 – Appearance of Sheet Surface After Bending Over a 1/16-in. Radius (1½T). Note extreme orange peeling and surface fissures. 12 ×

Fig. 6 – Appearance of Sheet Surface After Bending Over a 7/32-In. Radius (5½T). Although finish is improved, surface fissures are still evident. 12 ×

Fig. 7 – Appearance of Sheet Surface After Bending a Polished Blank Over a ⅛-in. Radius (3T). Orange peeling and surface fissures are still present. 12 ×

to a depth of at least 0.002 in. to remove the serrated edge.

Machinability Similar to Stainless

We determined drilling and milling (profile) characteristics using a standard drill press with a force-gage attachment and a standard milling machine.

Dry, hand-feed techniques and a 135° split-point, No. 18 Morse drill were used to make holes in the 0.040-in. sheet. At 18 surface ft. per min., an average of 72 lb. thrust was developed, an exit burr of 0.008 in. was produced and a 0.003-in. wear-land was obtained on the cutting lip after drilling 15 holes. At 33 surface ft. per min., an average of 62 lb. thrust was developed, an exit burr of 0.010 in. was produced and a 0.006-in. wear-land was obtained on the cutting lip after drilling 15 holes.

We employed a 1¾-in. diameter, 6-flute, right-spiral, right-hand cut, high-speed steel cutter in our end-milling tests. Speeds varied from 32 to 700 surface ft. per min. at 0.0005 to 0.007-in. chip loads (depth of cut per flute). Speeds of 32 to 92 surface ft. per min. at 0.005 to 0.002-in. chip loads gave the best results, maintaining a 40 to 60 rms. surface finish. A minimum amount of tool wear (0.002 to 0.005 in.) was encountered at these speeds. High speeds caused cutter burnout and work hardening of the material.

During drilling, D-31 is similar to austenitic stainless in its tendency to work harden. Drill life is slightly lower than might be expected for stainless. D-31 tends to pick up on the tool at various milling speeds and feeds, producing a poor surface finish; this can be improved if a trichloroethane cutting fluid is specified.

Bend Testing Not Conclusive

The limited amount of bend testing that we could do precluded determination of a minimum bend radius. Specimens were bent over radii varying from 1/32 in. (1T) to 7/32 in. (5½T). In no instance did a bend specimen fail catastrophically. We observed no splitting of the material or cracks through the thickness. However, bends made over a 1/32 or 1/16-in. radius produced a finish with an unacceptable "orange-peel" surface. The surface finish was improved by increasing the radius to 5/32 or 7/32 in. but orange peeling was not eliminated completely (see Fig. 5 and 6).

A specimen was then mechanically polished and tested. Prior to bending, macroscopic

examination revealed a minute network of imperfections (surface fissures) on the polished surface. After bending over a ⅛-in. radius, a coarse surface finish was again obtained, as shown in Fig. 7.

Formability Obtained Theoretically

No forming could be done with the amount of material available; forming parameters were obtained by constructing theoretical formability curves from mechanical property data.

Subsize tensile specimens, tested at room temperature, gave information used in constructing curves for contour stretch forming, rubber stretch-flange forming, and rubber shrink-flange forming. The formulas employed are given in Table II.

Figure 8 illustrates the contour parameters of flange height, h, material thickness, t, and radius of curvature, r. To construct the curves, two dimensionless parameters, h/r and h/t, are related to the mechanical properties of D-31 sheet, using the formulas in Table II.

If the flange height, radius of curvature and blank thickness of a contoured part are known, the part can be represented as a point on the proper formability chart. If the point falls within the cross-hatched area on the curve, this contour can be successfully formed.

Figure 9 compares the formability of rolled D-31 sheet in the stress-relieved condition with 7075-W aluminum alloy sheet. These curves indicate that D-31 has forming characteristics approaching that of 7075, which, of course, possesses excellent formability in the as-quenched temper.

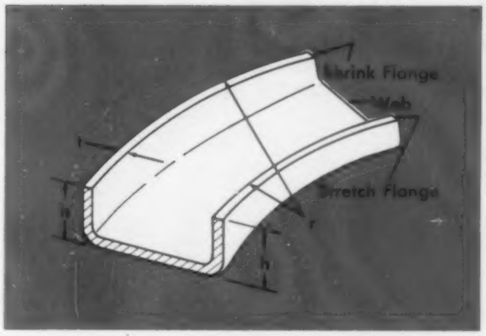


Fig. 8 – Contour Parameters for a Flanged Part To Be Produced by Rubber Press-Forming

Table II – Formulas Used in Constructing Formability Curves (See Fig. 9)

Horizontal Line	Point "A"	Point "B"
	Contour Stretch Forming	
$\frac{h}{r} = \frac{1}{1.95} \ln\left(\frac{1}{1\text{-RA}}\right)$	$\frac{h}{t} = \left[46.67\,\frac{E}{S_{ty}}\right]^{2/5}$	$\frac{h}{r} = 0.0105\,\sqrt{\frac{h}{t}}$
	Rubber Stretch-Flange Forming	
$\frac{h}{r} = \frac{1}{1.95} \ln\left(\frac{1}{1\text{-RA}}\right)$	$\frac{h}{t} = \left[10.24\,\frac{E}{S_{ty}}\right]^{2/5}$	$\frac{h}{r} = 0.0152\,\sqrt{\frac{h}{t}}$
	Rubber Shrink-Flange Forming	
$\frac{h}{r} = \frac{10^3}{S_{cy}}$	$\frac{h}{t} = 0.006\,\sqrt{E}$	

h = flange height, in.
r = radius of curvature of the part, in.
t = sheet thickness, in.
RA = reduction in area, 29.5%.
E = modulus of elasticity, 15.5×10^6 psi.
S_{ty} = tensile yield strength, 115,000 psi.
S_{cy} = compressive yield strength (assumed equal to S_{ty}).

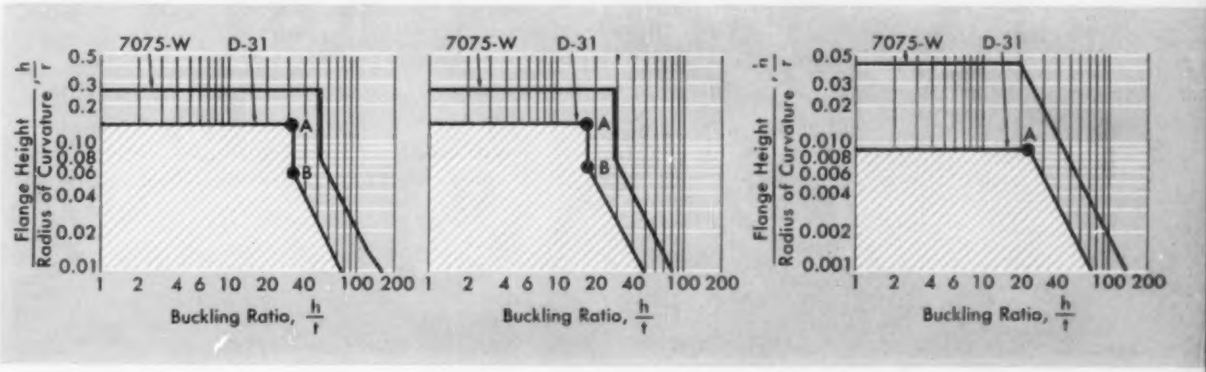


Fig. 9 – Contour Stretch Forming (Left), Rubber Stretch-Flange Forming (Center) and Rubber Shrink-Flange Forming (Right) of Stress-Relieved D-31 Versus 7075-W Sheet. Parts represented by points that fall within the cross-hatched area can be successfully formed. Formulas used in constructing formability curves are given in Table II

Furnace Brazing of Stainless Steel Assemblies

*By H. M. WEBBER**

Furnace brazing – employing a variety of protective atmospheres, furnaces and filler metals – offers a number of advantages. Many flux-free, nonporous joints can be brazed simultaneously and economically, dissimilar metals with wide thickness variations can be joined, and close tolerances can be held. (K8j; SS)

In industries producing modern hardware, such as missile and space vehicles, and nuclear and electronic components, furnace brazing is being used more and more for joining stainless steel assemblies. The gas or electrically heated furnaces usually operate with a suitable protective atmosphere or in vacuum. Even though heat for brazing can be provided by other means, such as gas torches or induction coils, certain considerations may justify selection of furnace brazing.

*Manager, Process Engineering Dept., Harper Electric Furnace Corp., Buffalo, N.Y.

For example, the process will bright braze stainless assemblies without a flux. Sound nonporous bonds are obtained and subsequent cleaning operations are avoided. Many joints (or many assemblies) can be brazed simultaneously, thereby reducing costs. The work is uniformly heated, providing assemblies with minimum internal stress. Dissimilar metals with widely varying thicknesses can be joined with ease. Components made of martensitic stainless can be furnace brazed and hardened simultaneously. Finally, results are reproducible and easily controlled within close tolerances. Thus, when multiple components are to be joined into an accurate assembly, furnace brazing gives uniformly high quality at moderate cost.

Fig. 1 – Two-Piece Valve Assembly, Made of Type 440 F Stainless, Prior to Brazing and Bright Hardening. The filler metal is a copper ring which is held in a groove in the flange after assembly. (Bendix Corp.)

Copper is usually selected as the filler metal in brazing stainless components which operate up to 700° F. (continuous service), or at higher temperatures for shorter times. Copper provides good joint strength and tightness at low cost. However, strength and oxidation resistance decrease with increasing temperature.

Most silver-brazing alloys have characteristics and uses which are similar. Typical is sterling silver (92.5% Ag, 7.5% Cu) with 0.2% Li added as a wetting agent. Widely used for continuous service up to 500° F. (higher temperatures for shorter times), the alloy readily flows on such difficult-to-wet base metals as 17-7 PH stainless. Successful results are obtained in dry hydrogen, argon, helium or vacuum, without a flux.

Three classes of nickel-base brazing alloys suitable for high-temperature (2000° F.) service are: *(a)* Ni-Cr-Si-B, *(b)* Ni-Si-B, and *(c)* Ni-Cr-Si. Boron depresses the melting point, is a hardener and strengthener, and aids wetting and flow. But alloys containing boron are to be avoided for nuclear applications because boron has a high neutron cross section, which lowers reactor efficiency.

Among numerous other filler metals useful for stainless brazing is the eutectic gold-nickel alloy (82 Au, 18 Ni). The relatively low flow point of 1740° F. provides excellent wetting characteristics and minimizes adverse effects on the base metal – such as solution and intergranular penetration by

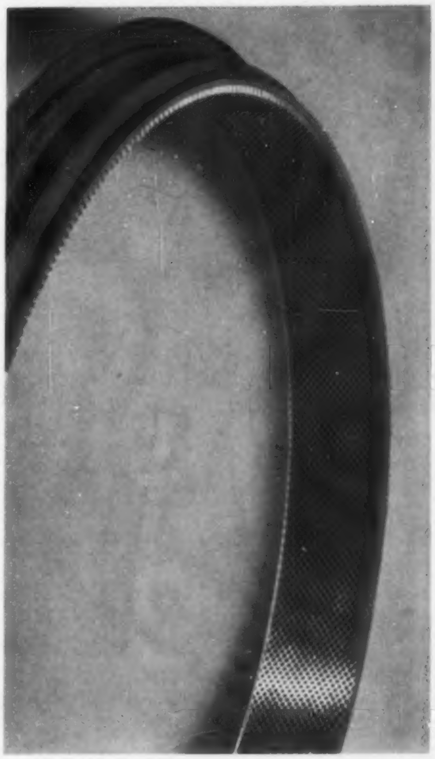
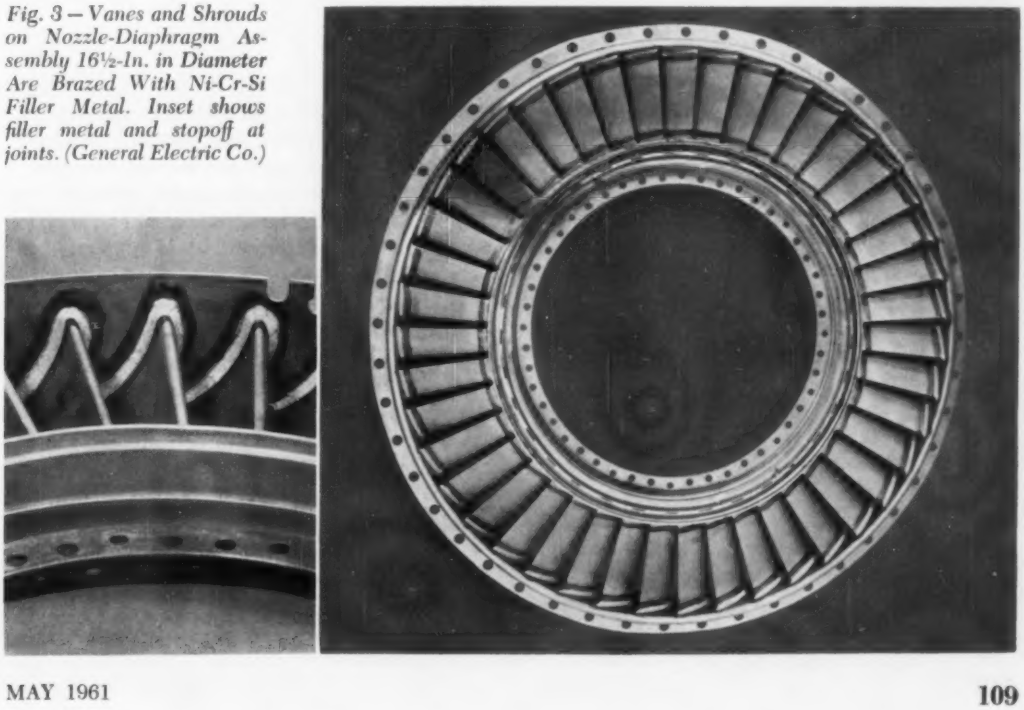


Fig. 2 – Open-Face Honeycomb Seal for Gas Turbines Made of Inconel and Type 321 Sheet. (Solar Aircraft Co.)

Fig. 3 – Vanes and Shrouds on Nozzle-Diaphragm Assembly 16½-In. in Diameter Are Brazed With Ni-Cr-Si Filler Metal. Inset shows filler metal and stopoff at joints. (General Electric Co.)



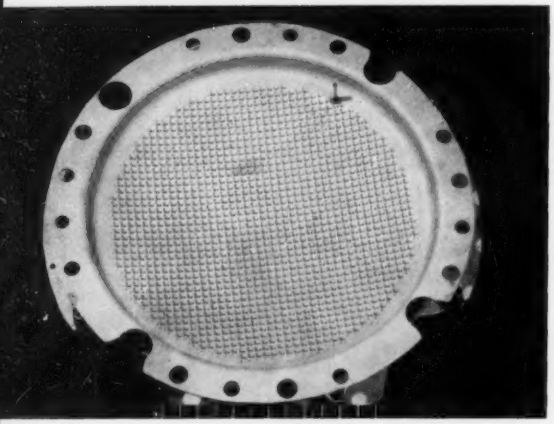


Fig. 4 – Furnace-Brazed Injector Head, Made of AM 350 and Nickel Alloy Parts, Will Be Mounted in Rocket Thrust Chamber. (Solar Aircraft Co.)

Fig. 5 – Tube-to-Header Heat Exchanger Assemblies Containing Thin-Walled 347 Stainless Tubes Are Ready for Furnace Brazing. (Solar Aircraft Co.)

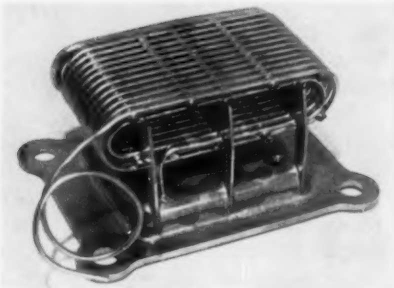


Fig. 6 – Coiled Tube Heat Exchanger of Type 304 Stainless Bonded With a Ni-Cr-Si Filler Slurry

molten filler metal and grain growth. The alloy provides good strength, toughness, ductility and oxidation resistance up to 1500° F. and is not critical with respect to joint clearances, quantity of filler metal, heating rate or time at brazing temperature. In the manufacture of jet engines, gold-nickel is used on vane-and-shroud assemblies and fuel-manifold assemblies.

Filler metals are supplied in many forms. Copper is available as wire, sheet, strip, and powder paste; it may also be electroplated. Silver-brazing alloys and the gold-nickel alloy come in wire, sheet and powder forms. Nickel-base brazing alloys are utilized mostly as powder in a liquid carrier of acrylic resin mixed with acetone. This slurry can be brushed, sprayed, or ejected from a hypodermic needle. Sometimes the dry metal powder is applied at the joints and coated with acryloid cement from an eye dropper. Nickel-base powders are applied as molten spray from an oxyacetylene gun; specific alloys can be electroplated. Powders are also available as plastic-bonded wire, sintered rings, sheet and tape.

Base-Metal Characteristics

All of the 300, 400 and 500 series of stainless steels, as well as other heat-resisting steels and superalloys are being furnace brazed successfully. Most of the stainless and heat-resisting alloys are relatively easy to braze because their compositions do not include troublesome elements in amounts high enough to create problems. Alloying elements such as titanium and aluminum, however, cause brazing difficulties because they oxidize in pure, dry hydrogen at the lowest dew points commercially available. Many superalloys contain sufficient titanium or aluminum to place them in this difficult category. In some instances, extra fast heating cycles minimize formation of objectionable oxides in dry hydrogen. Usually, however, a special treatment for surface protection is applied, such as nickel plating, flame spraying, fluxing, or pre-oxidizing followed by pickling.

Good filler-metal flow and superior joints have been obtained by brazing such superalloys in vacuum without any preliminary surface preparation other than cleaning. The general procedure is to pump down to the lowest pressure within the capacity of the equipment, such as 0.5 micron or lower, and hold throughout the heating and cooling cycle.

Many stainless steels are subject to carbide precipitation when cooled slowly from brazing

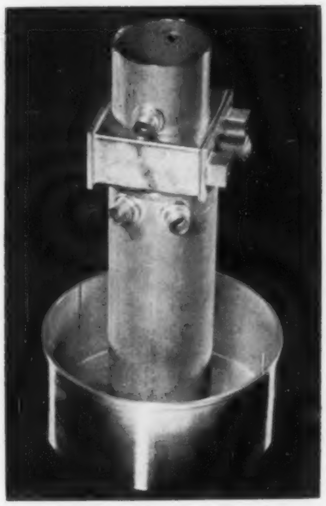


Fig. 7 – Components of Power Microwave Tube Are Joined in Several Steps by Brazing at Successively Lower Temperatures With Different Alloys. (Eitel-McCullough, Inc.)

Fig. 8 – Connector for Magnetron Tube Made of Inconel "X" and Type 302 Stainless Steel

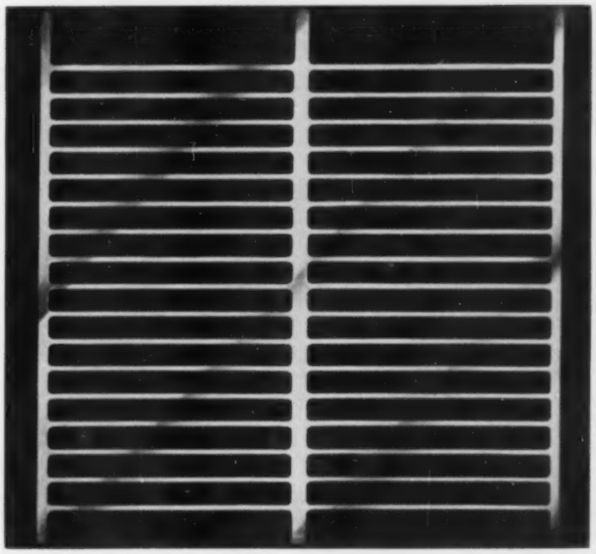


Fig. 9 – Cross-Section of Type 304 Stainless Fuel Element for a Nuclear Power Reactor Showing Brazed Joints of Ni-Cr-Si Filler Metal. (M & C Nuclear, Inc.)

to room temperature. For example, slow cooling is experienced in a continuous furnace as the work moves through the brick throat between heating and cooling chambers. Under severe atmosphere and stress conditions, carbide precipitation can affect corrosion resistance and physical properties adversely. In such instances, results are improved by specifying stabilized stainless steels, which are not critical in this respect. Another approach is to fast cool. However, it is not necessary to fast chill when hardening martensitic stainless steels after brazing.

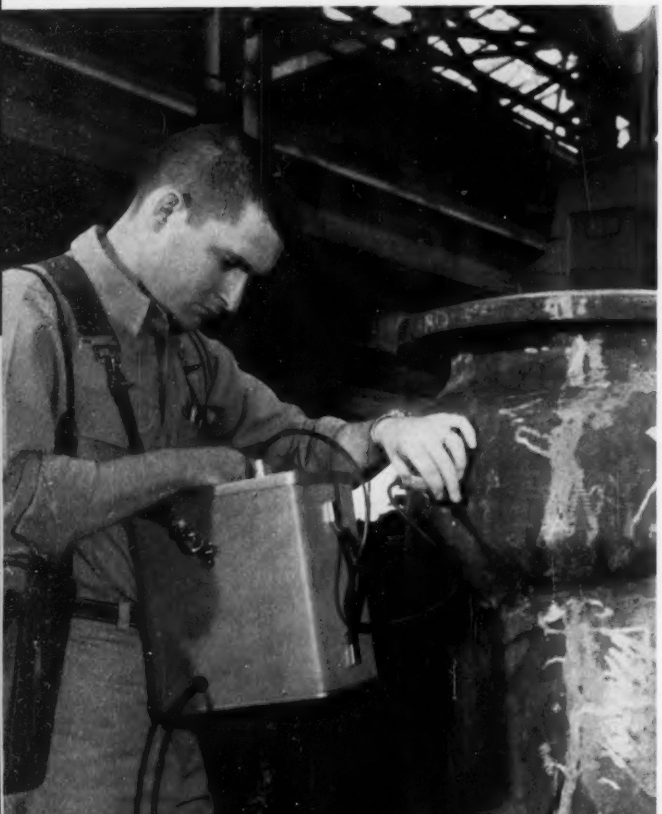
A Variety of Protective Atmospheres

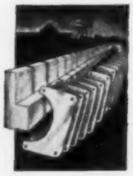
Protective atmospheres for bright brazing stainless steels include dry hydrogen, dissociated ammonia, argon, helium or vacuum.

Pure, dry hydrogen, rather than dissociated ammonia, is used for critical work, particularly with base metals and filler metals which contain elements that can form refractory oxides or nitrides in the presence of moisture or nitrogen. This is especially true for long heating cycles or high temperatures, or both. When hydrogen or other flammable gas atmospheres are used for brazing, most furnaces are purged with nitrogen, argon or helium before starting up and shutting down, as a safety precaution.

Dissociated ammonia is widely employed in bright brazing because it costs less than hydrogen. Its use is limited to noncritical work, particularly base metals and filler metals which do not contain reactive elements in appreciable quantities, and for jobs with shorter brazing cycles. Nitrogen in the dry state will nitride chromium, titanium, columbium and aluminum in base metals and chromium and boron in Ni-Cr-Si-B filler alloys (producing poor wetting and flow characteristics). In many instances, nitriding of the base metal is insignificant. However, it is detri- *(Continued on p. 118)*

Fig. 1 – Determining the Wall Thickness of an Irregularly Shaped Casting





Short Runs

Measuring Thicknesses in Hard-to-Reach Areas

If conventional methods had to be depended upon, it would be extremely difficult to measure the wall thickness variations in the casting shown in Fig. 1. However, the illustrated portable ultrasonic instrument* makes the job simple for engineers at American Cast Iron Pipe Co., where the casting was made. The probe is merely placed at the point where the thickness is to be determined. Then, a slight turn of a dial produces a direct reading of the dimension.

The transistorized device can measure thicknesses from 0.025 to 3 in. in almost any material that transmits ultrasonics – steel, cast iron, brass, magnesium, glass, celluloid, and hard rubber are but a few of them. Through its use, areas of corrosion or wear can be located on tanks, the hulls of ships, wing skins of airplanes and other structures which must be examined from one side alone. At American Cast Iron Pipe Co. this unit is also used to control the dimensions of special products (such as long pipe manufactured to close tolerances) from the as-cast condition through final machining.

*Sonizon SO-300, Magnaflux Corp., Chicago.

LETTERS TO THE EDITOR

Predicting Very-Short-Time Creep Behavior for Missiles

"Predicting Very-Short-Time Creep Behavior for Missiles", by S. F. Frederick (*Metal Progress,* March 1961 p. 88), was written to show that time-temperature parameters could be applied to very-short-time data. However, in the curves published with the article, the points indicating these data were omitted inadvertently. The corrected curves, included here, prove that the theoretical parameters coincide closely with actual creep data.

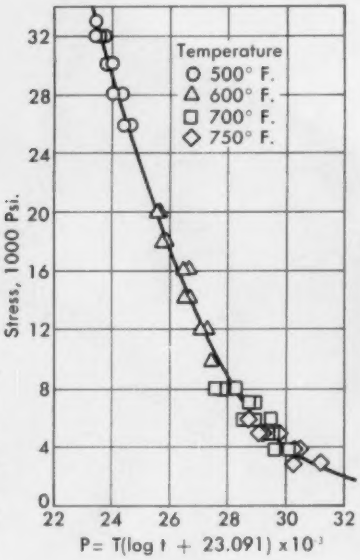


Fig. 1 — Larson-Miller Curve for Alclad 2024-T 81. For this curve, temperatures range from 500 to 750° F., times from 2 to 800 sec. for all illustrated curves, and the parameter units (for all curves) are "seconds" for time and °R. for temperature (except where noted)

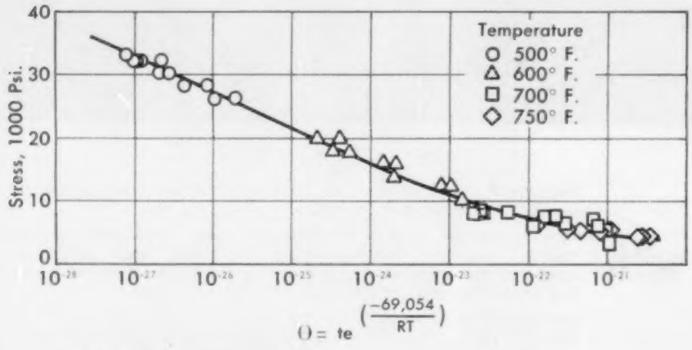


Fig. 2 — Dorn Curve for Alclad 2024-T 81. Temperature range: 500 to 750° F.

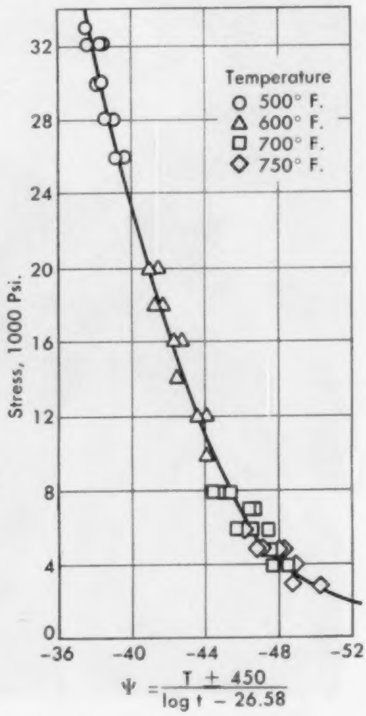
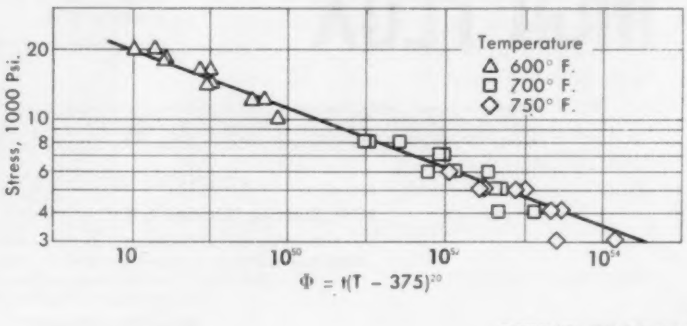
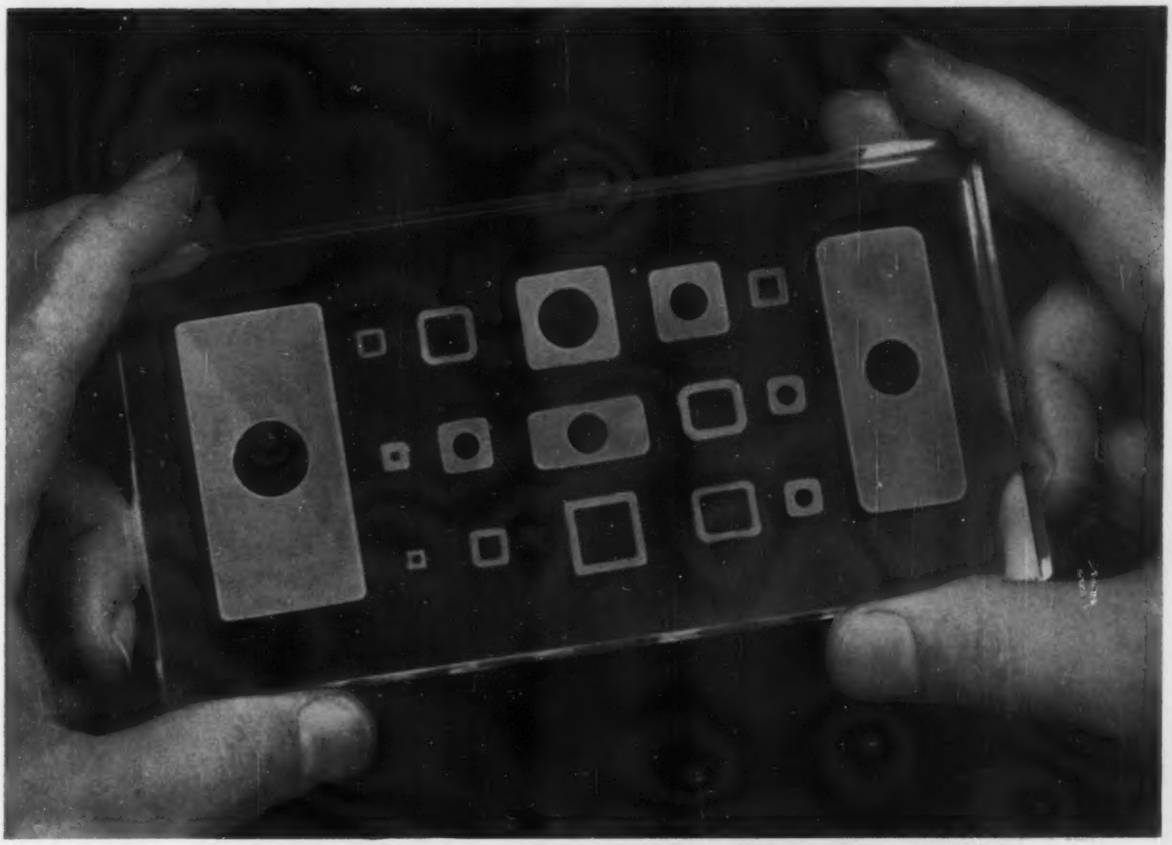


Fig. 3 — Manson-Haferd Curve for Alclad 2024-T 81. Temperature range: 500 to 750° F. (Parameter temperature, °F.)

Fig. 4 — Graham-Walles Curve for Alclad 2024-T 81. Temperature range: 600 to 750° F.



a new look at hollow conductors



Cross sections of some typical hollow copper conductors produced by Anaconda American Brass Company

Anaconda makes conductors to meet new needs in fluid cooling of windings, bus, and heat sinks

The high electrical and thermal conductivities of copper —the highest among commercial metals—are being utilized in fluid-cooled conductors to do a host of new jobs.

Fluid-cooled copper conductors are making possible more compact electrical assemblies to handle high current densities and uses are growing rapidly in large electrical equipment. Generator output, for example, can be greatly increased, without increasing frame size, by cooling the stator bars.

In such applications as heat sinks for power rectifiers and induction furnace coils—where controlled heat dissipation is essential—the use of fluid-cooled copper conductors is a natural.

Water-cooled windings produce the very high flux densities needed in the compact equipment for the ceramic magnet manufacturing process. The current range in these "solenoids" is from a few hundred to about 2000 amperes.

Of course, the most spectacular applications of fluid-cooled conductors are in nuclear physics magnets. These hollow conductors range from tube .182" square O.D. x .083 square I.D. to heavy rectangular bars with a round core for water cooling.

TECHNICAL ASSISTANCE. The cross sections of hollow conductors shown above indicate but a few of the many ways in which Anaconda American Brass is shaping copper to meet these new needs. Whatever your requirement, Anaconda specialists will gladly help you work out the size and shape best adapted to your needs. For such assistance, see your Anaconda American Brass representative, or write: Anaconda American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

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Anaconda American Brass Company

Circle 1815 on Page 48-B

Circle 1816 on Page 48-B

Inspecting Jet Engine Parts With Eddy Currents

SCHENECTADY, N.Y.

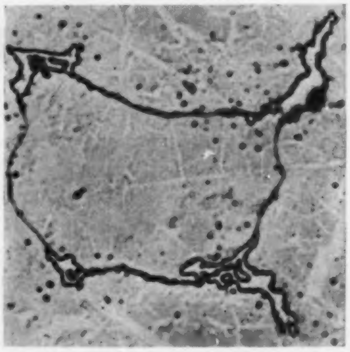
R. L. Lipe is to be complimented on his excellent article under the above title in *Metal Progress* for March 1961. However, there is one comment. The etchant mentioned in Fig. 2 (92% HCL, 5% H_2SO_4, 3% HNO_3) is not a modified Tucker's etchant. This etchant was developed in 1946 by R. T. Knaggs and the writer for etching Vitallium (a dental and surgical alloy similar to Haynes Stellite No. 21), S-816, S-590 and similar alloys. Tucker's etchant consists of HF, HCl, HNO_3, and H_2O; it is used essentially on aluminum alloys.

E. D. REILLY
Metallurgy Unit
Materials and Processes Laboratory
Large Steam Turbine-Generator Dept.
General Electric Co.

Metallographic Map

PORTLAND, ORE.

While conducting a metallographic examination on some austenitic manganese steel, we found a combination of grain boundaries and carbide precipitate bearing a strong resemblance to a map of the continental United States. The specimen was etched with 5% nital and the original photomicrograph was taken at 200×; the reproduction above was enlarged to 600 ×



FREDERICK SMITH
RICHARD CRUM
Metallurgical Department
Esco Corp.

Circle 1817 on Page 48-B

Furnace Brazing . . .

(Continued from p. 111)

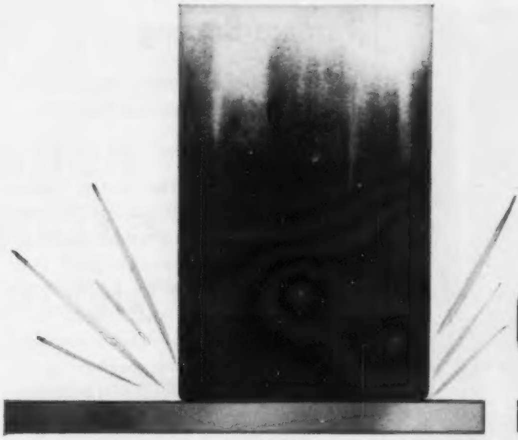
mental on parts which undergo long-time, high-temperature cycles or on exceptionally thin metals, such as foil sections in honeycomb panels.

Since argon and helium are chemically inert, they will not combine with metallic elements, even at high temperatures. Nor will they react with carbon in supports and fixtures (as will hydrogen) to carry carbon to the work in the gaseous phase. Thus purified argon and helium are sometimes used for furnace brazing.

Vacuum brazing affords certain advantages and is particularly adaptable to the superalloys and other metals containing high percentages of the "difficult" elements. Not only is the wetting action superior – oxide and nitride formation is eliminated – but the bond is gas-free and therefore uniformly tight and strong. Bond ductility is generally improved, and costs are lower, since gas consumption is reduced.

Brazing furnaces, electric or gas heated, are of the batch or continuous type. To avoid contamination of the pure, dry atmosphere by water vapor or air from the furnace brickwork, it is often necessary to enclose the work in retorts or muffles. Reaction of hydrogen with iron oxide present in refractories produces objectionable water vapor at elevated temperatures. Gas-fired furnaces require retorts or muffles to separate the protective atmosphere from the heat source. High-purity alumina, which contains no reducible constituents such as iron oxide, is sometimes used in linings of electric furnaces. This eliminates need for a muffle and permits heating elements to radiate heat directly to the work.

Representative furnace types for brazing stainless steel are box, pusher, hump mesh-belt, pit, bell, bell-car, elevator and car. Furnace selection depends upon size and weight of assemblies; nature of the work, such as experimental or production; availability of a crane and headroom; ability of assemblies to withstand movement on cars prior to brazing; types of base and filler metals; time-temperature cycles desired; and the economics of the operation. The relationship of these factors is illustrated below in discussing various stainless steel assem-



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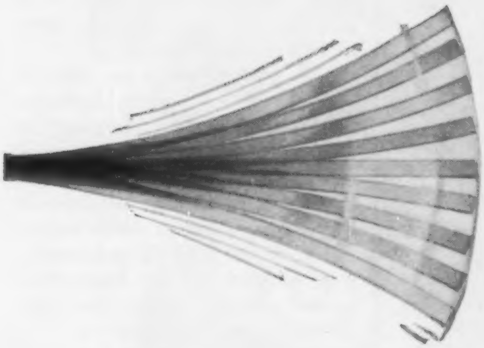

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Timken consumable electrode vacuum arc steel is available in ingots up to 24″ in diameter and weighing up to 10,000 lbs.—and in bars and rotary-pierced tubing in a wide range of alloy and stainless analyses. Let our metallurgists help you on applications for Timken vacuum arc steel, in developing lighter, stronger parts. Call or write: The Timken Roller Bearing Company, Steel and Tube Division, Canton 6, Ohio. Cable address: "TIMROSCO". Makers of Tapered Roller Bearings, Fine Alloy Steel and Removable Rock Bits.

TIMKEN®
FINE ALLOY STEEL

Circle 1819 on Page 48-B

Furnace Brazing . . .

blies and the equipment required in joining them by furnace brazing.

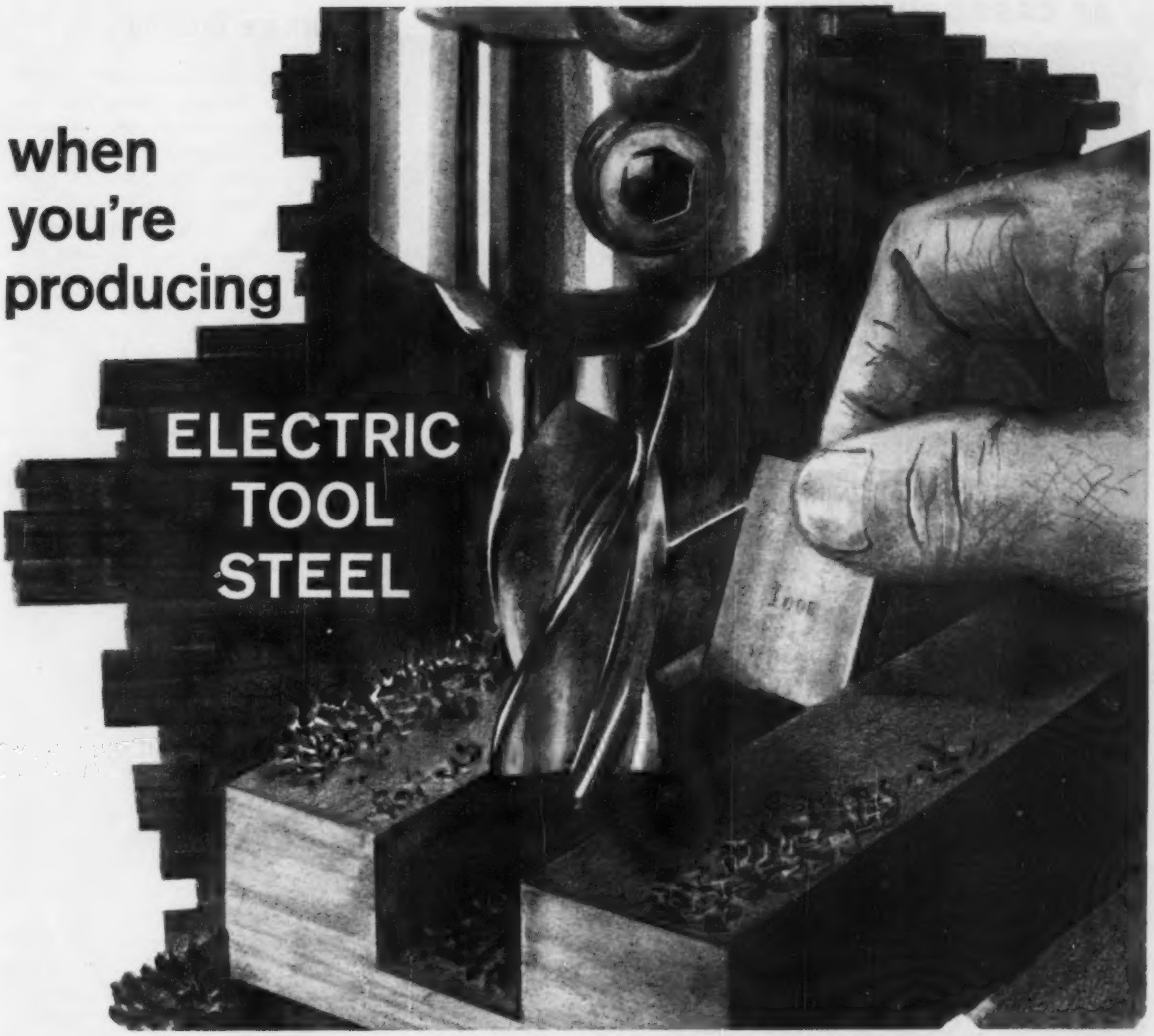
Aircraft Applications

Cutoff Valve – The cutoff valve assembly shown in Fig. 1 (p. 108) is made of Type 440 F stainless. It is simultaneously copper brazed and bright hardened to Rockwell C-57 at 2010° F. in a dissociated ammonia atmosphere. The two-piece construction permits machining of a cavity in the body, and facilitates holding critical dimensions on the internal orifice and concentricity between orifice and barrel. The part would be difficult and costly, if not impossible, to make any other way. Since hardening is required, the brazing cost can be considered nominal. The work is loaded in trays and pushed (intermittently) through a box furnace containing an alloy muffle. Purging chambers at both ends maintain the high-purity dissociated ammonia atmosphere.

This type of work can also be brazed in a box-type dry hydrogen furnace with purging chambers but without a muffle. The heating chamber is lined with high-purity alumina brick and has molybdenum rod heating elements which radiate directly to the work. This furnace is well adapted to high-temperature brazing (3000° F. max.) where muffle maintenance is a problem.

For continuous brazing of small stainless assemblies, a hump mesh-belt furnace is employed. The adjustable speed conveyer assures constant time-temperature cycles, steady flow of work, and frequently eliminates tray handling and maintenance. With the elevated heating chamber providing a natural atmosphere seal, hydrogen consumption is but a fraction of that for a straight-through mesh-belt furnace. Some hump furnaces have an alloy muffle throughout the heating chamber; others are built without muffles, having high-purity linings for holding hydrogen atmospheres with a low dew point.

Honeycomb Sandwich – Portions of supersonic planes including parts of wings and engine nacelles operate for short times at temperatures of 900° F. or higher, which precludes the use of aluminum. Stainless steel honeycomb structures are being specified to obtain maximum



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Furnace Brazing . . .

strength with minimum weight. Furnace brazing – using box car, bell or elevator furnaces – is one of the methods used in fabricating such panels successfully. One of the base metals currently used is 17-7 PH stainless. This alloy can be brazed with sterling silver (containing 0.2% Li) at 1680° F. in a sheet-metal container which is first evacuated, then filled with argon and partially evacuated to a pressure of 15 in. Hg.

Honeycomb Seal – Another useful adaptation of lightweight honeycomb construction is in an open-face honeycomb seal for gas turbines, shown in Fig. 2 (p. 109). Surrounding a rotor stage and mounted in the engine housing, it provides the closest thing to a "zero clearance" dynamic seal, desirable for high efficiency. It is installed without clearance, and the rotor cuts a smooth path into it.

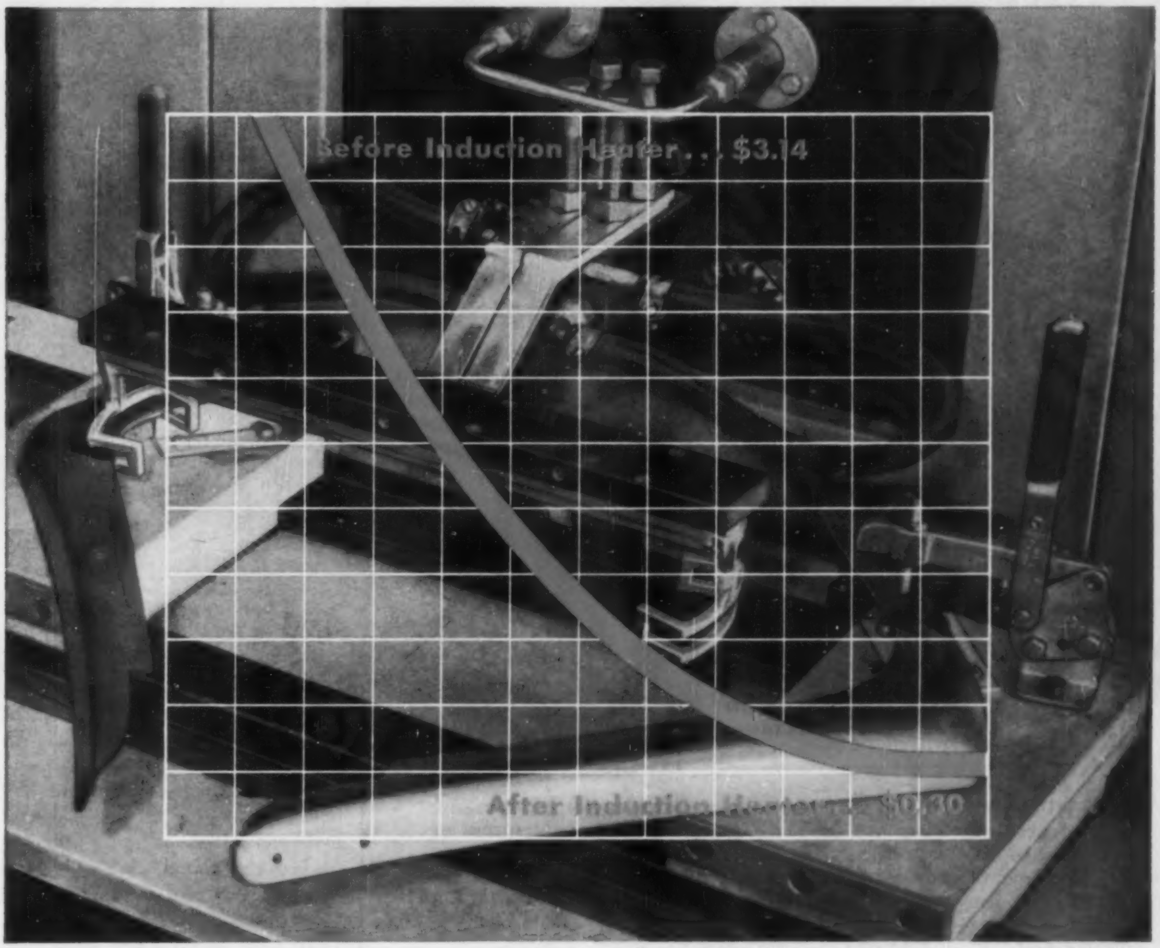
The inner 0.093-in. Inconel band and the 0.005-in. foil Type 321 honeycombs (1/8 in. square) were first brazed to make an open-face sandwich. The outer shroud shown was fabricated on a special bellows-forming machine from Inconel "W" sheet, 0.043-in. thick.

After brazing at 2050° F., the open-face seal ring was expanded to fit the outer shroud and then brazed to it using a slightly lower-melting brazing alloy. The composition of the brazing alloy used for the second brazing operation contained an additional 0.5% B and 0.8% Si over the original Ni-Cr-Mn-Si-B, permitting the second brazing at 1900° F.

The high mechanical properties of heat treated Inconel "W" make this double-brazed seal very attractive from the standpoint of strength-to-weight ratio and production economy. Assemblies of this nature are commonly brazed in batch-type furnaces, such as an elevator furnace with an alloy retort. The work is loaded on a pedestal on a metal-covered base. A retort covers the work and rests on a water-cooled neoprene ring at the bottom of a car. Dry hydrogen circulates through the retort during heating and cooling.

Nozzle-Diaphragm – Another jet-engine part commonly furnace brazed is the nozzle-diaphragm assembly shown in Fig. 3 (p. 109). While construction details vary, such

ALLIS-CHALMERS



Back braces of folding metal chairs being stress relieved by Allis-Chalmers induction heater. Two-position fixture speeds production.

Allis-Chalmers induction heater replaced oxyacetylene torch

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• • •

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Circle 1823 on Page 48-B

Furnace Brazing . . .

assemblies consist essentially of vanes and shrouds. Those which operate in the compressor stator are sometimes brazed with copper. The one illustrated, for the second turbine stage of the J-85 engine, operates at elevated temperature and is brazed with vacuum-melted Ni-Cr-Si filler metal. Vanes are sheet metal, with sheet-metal inserts individually furnace brazed into them before final assembly. In the close-up, note the confinement of the filler metal at the joints by means of dark stopoff material painted on the adjoining surfaces. Base metal is Haynes Alloy No. 25 (L 605), brazing temperature is 2150° F. (on the work), and the atmosphere is dry hydrogen.

This assembly could also be brazed in a vacuum furnace equipped with double pumps to maintain pressures of 750 to 1000 microns outside the retort and 0.2 to 0.4 micron within it. With a 4000-lb. load, total cycle time is about 8 hr.

Missile and Space Vehicle Uses

Injector – The N.A.S.A. injector for fuel and oxidizer, shown in Fig. 4 (p. 110), is mounted at the head of a thrust chamber in a rocket. In service, the tubes deliver oxygen to the combustion chamber, and tiny holes surrounding the tubes deliver hydrogen. It is a complex assembly made of two dished heads of AM 350 stainless, between which is a nickel face plate and some stainless spacers, Over 1300 nickel tubes are brazed into holes in the plates, using copper-powder paste. Dry hydrogen is the atmosphere in the retort of an electric elevator furnace. This rigid, lightweight structure is made with greater uniformity and at substantially lower cost than would be possible with manual brazing.

Heat Exchangers – A batch of lightweight, tube-to-header heat exchangers is shown in Fig. 5 (p. 110), ready for brazing. This and similar designs are currently used in gas-to-gas, gas-to-liquid and liquid-to-liquid systems, for air conditioning and other fluid heat-transfer applications in space vehicles. Containing 660 thin-walled Type 347 tubes, the furnace-brazed assembly is superior to a welded one and less costly. The unit is hydrogen brazed in an elevator furnace at 1950 to 2000° F.

Furnace Brazing . . .

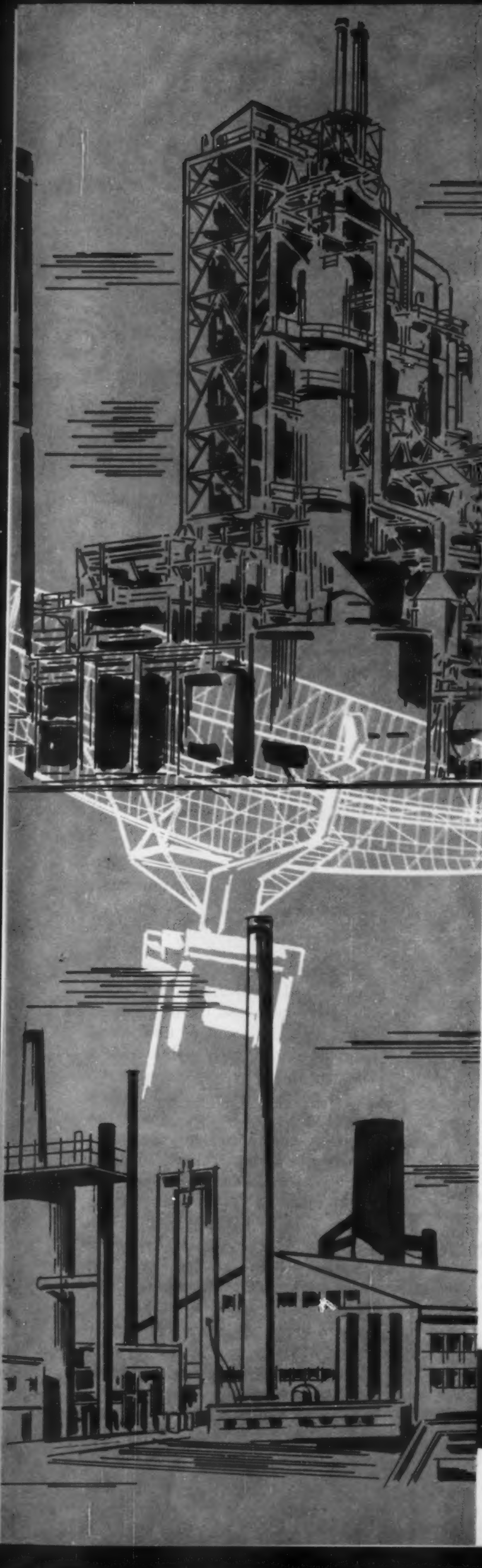
utilizing a nickel-base filler metal slurry that is sprayed or brushed on the Type 321 header faces. To minimize diffusion of filler metal into the thin base metal, the time at brazing temperature is kept at a minimum.

A different type of heat exchanger for missiles and space vehicles (Fig. 6, p. 110) contains three brackets, pressed into slots in a 3½-in. long base plate, supporting a double coil of ⅛-in. O.D. thin-walled tubing and ten spacer tubes. There are 345 joints in this Type 304 stainless assembly, bonded with a Ni-Cr-Si filler slurry. About 20 assemblies are brazed simultaneously in a pit-type radiation-shield (cold wall) vacuum furnace at 2175° F., operating at 0.2 micron pressure. After being heated in the lower part of the furnace, the load is lifted up to the water-jacketed cooling chamber. Then the two chambers are separated and the load is removed and replaced. The total heating and cooling cycle is 2 to 2½ hr. To braze the assemblies in hydrogen would require vacuum purging the tubes in advance to remove air and to assure bright internal surfaces. Vacuum brazing eliminates this.

Electronic Applications

Power Microwave Tubes – Furnace brazing is widely used in vacuum-tube work involving metal-to-metal and metal-to-ceramic seals. The fluxless bonds produced help in meeting stringent requirements for vacuum tightness and cleanliness. Of particular interest is the step-brazing technique used in the manufacture of klystrons or power microwave tubes (Fig. 7, p. 111). Klystrons are built in a variety of designs and sizes, some up to several feet high. They are made of a number of parts (or furnace-brazed subassemblies) which may consist of several dissimilar materials such as oxygen-free copper, mild or stainless steel, Kovar, Monel, nickel or metalized ceramics.

The first braze on the assembly is made with copper at 2050° F. to bond the inner and outer stainless tubes to the stainless disk in the base. Subsequent joints are brazed with a Cu-Ni-Au alloy at 1945° F., and then at 1910° F. using a Cu-Au al-



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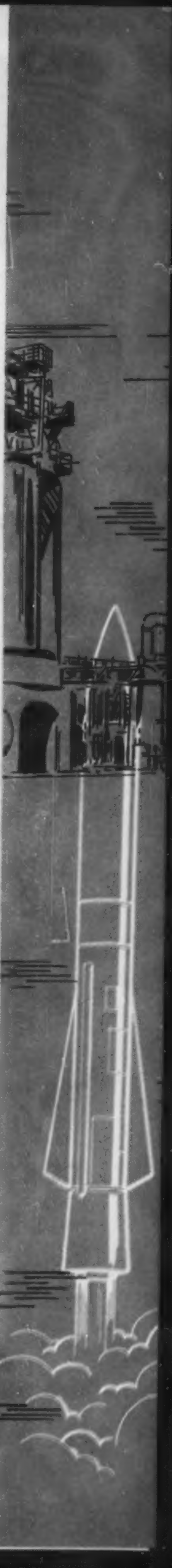

Circle 1827 on Page 48-B

Furnace Brazing . . .

loy. Other filler materials are available for several additional steps of reduced-temperature brazing where necessary. Such assemblies usually are brazed in dry hydrogen or dissociated ammonia employing bell or elevator furnaces with retorts.

Magnetron Tube – Figure 8 (p. 111) shows a connector for magnetron tubes, made of two different materials of widely different thickness. The 1½-in. diameter flange and center tube are Type 302 stainless; the thin spring is Inconel "X".

Since Inconel "X" is difficult to braze in dry hydrogen, because of of its 2.5% Ti and 0.7% Al content, a radiation-shield vacuum furnace is employed. A number of assemblies are included in each load with the furnace temperature at 2175° F. and the pressure at 0.2 micron. Wetting is excellent, without the aid of flux or a special surface treatment. After brazing with Ni-Cr-Si filler metal the assembly is given an additional heat treatment to harden the Inconel "X".

Nuclear Applications

A cross section of a 34-plate brazed fuel element for nuclear power reactors is illustrated in Fig. 9 (p. 111). Such an assembly consists of long, thin fuel plates of Type 304 stainless, fitted into grooved sideplates and centerplates. Supported by an intricate fixture inside a sealed retort, the assembly is brazed with Ni-Cr-Si alloy in a box furnace at 2150° F. using a dry-hydrogen atmosphere. Specifications are critical on clearance dimensions between individual plates, flatness, straightness, amount of filler metal, and fillets and gaps – but furnace brazing meets all requirements.

In another type of fuel element construction, seamless tubes are rigidly positioned and uniformly spaced by brazed honeycomb grids. A typical core assembly consists of 138 tubes of Type 348 stainless, ¼ in. O.D. by 0.005 in. wall. High-velocity, high-pressure helium is used as a heat-exchange fluid. Corrosion-resistant nickel-base filler metal secures the tubes to the spacer disks; brazing is carried out in hydrogen using an elevator furnace. A high degree of rigidity is achieved, yet the honeycomb spacer design is extremely lightweight.

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Circle 1829 on Page 48-B

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Circle 1830 on Page 48-B

PERSONAL MENTION

S. C. Guillan

LIEUT.-COL. S. C. GUILLAN retired from the secretaryship of the Institute of Metals on April 30, after 50 years with the Institute.

Charles Guillan was educated privately and at St. Dunstan's College, and was intended to enter the business of his father, who was a silk merchant in London. However, the publication activities of the Institute of Metals attracted him and in April 1911 he became the first junior assistant to the secretary of the Institute. The Institute gave him the opportunity to study metallurgy by day and in the evenings at what is now Sir John Cass College.

His training was interrupted by the outbreak of war in 1915; he served in the infantry in the Norfolk Regiment, returning to civilian life in 1920. Rejoining the Institute, he became the first assistant secretary in 1926 and editor of publications in 1937. However, his regiment was mobilized in 1939 and he served in the Royal Artillery, until retiring in 1946 as a lieutenant-colonel.

Returning to the Institute's staff as assistant secretary and editor, he was appointed secretary in 1947.

The work with the Institute which has given him most satisfaction has been the development of *Metallurgical Abstracts* from an unorganized survey of the literature to a publication of world-wide repute and the building up of a large overseas membership, making the Institute truly international in character.

Arnold L. Rustay, technical director, Wyman-Gordon Co., Worcester, Mass. – elected a vice-president.

Choh-Yi Ang – from director of materials laboratories, P. R. Mallory & Co., Inc., Indianapolis, to manager of the newly organized physics research laboratory of Telecomputing Corp., Los Angeles.

Richard C. Cole, vice-president of manufacturing for Vitro Chemical Co. and vice-president of Vitro Minerals Corp. – named executive vice-president and general manager of White Pine Copper Co., a subsidiary of Copper Range Co.

Howard H. McIntosh – now unit chief of the metallic materials unit at the Utah Div., Thiokol Chemical Corp., Brigham City, Utah.

Alvin G. Cook – from assistant to the chief corporation metallurgist to coordinator, product specifications, at the Brackenridge, Pa., works of Allegheny Ludlum Steel Corp.

Roland C. Crans – now assistant chief engineer for Holcroft & Co., Detroit.

C. O. Young – from manager of metallurgical engineering to manager, lamp parts department, at the lamp division of Westinghouse Electric Corp., Bloomfield, N.J.

Frank A. Forward

FRANK A. FORWARD, head of the Department of Metallurgy at the University of British Columbia in Vancouver, received the 1960 John Scott Award from the City of Philadelphia for his discovery of the Forward Process, a leaching process for low-grade nickel ore. The award, which consists of a copper medallion and a $1000 cash prize, was established in 1816 by John Scott, a chemist of Edinburgh, Scotland. On his death he willed $4000 to establish periodical awards to "the most deserving", specifying that no more than $20.00 was to be given each time. In the intervening nearly two centuries, this sum has grown to $110,000 and the courts have permitted a modification of the original deed, so that two or three sizable monetary awards are made each year for advances in all fields of human endeavor. The award to Professor Forward is the fourth to be made for purely metallurgical research and achievement; other recipients have included Marie Curie, Orville Wright and Guglielmo Marconi.

Professor Forward has been on the

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Personals . . .

faculty of the University of British Columbia for nearly 26 years. After graduating with honors in chemical engineering from the University of Toronto in 1924, he began his career in industry (which included tenures with the Consolidated Mining and Smelting Co. and British Columbia Nickel Mines) and since joining the University faculty has continued consultation work.

Among his other awards are the McCharles Prize (1955) of the University of Toronto and the Inco Medal (1955) of the Canadian Institute of Mining and Metallurgy. He has held high office in many technical groups including the Canadian Institute of Mining and Metallurgy and the Assoc. of Professional Engineers of British Columbia. His A.S.M. activities have included chairmanship of the British Columbia Chapter, Canadian representative on the A.S.M. committee on Engineering Education and guest lecturer for the Toronto Chapter.

Harold C. Stone – from chief metallurgist, Le Tourneau Westinghouse Co., Peoria, Ill., to chief metallurgist, American Steel Treating Co., Crystal Lake, Ill.

Steve Stasko – now chief metallurgist of the Mackintosh-Hemphill Div., E. W. Bliss Co., Pittsburgh.

Thomas A. Prater – now manager of the process laboratories unit of the General Electric Research Laboratory, Schenectady, N.Y.

James W. Perry – from director of the Documentation Center at Western Reserve University to the systems engineering department of the college of engineering at the University of Arizona.

W. Edward Macer – from manager of sales engineering, heating elements, to product sales manager at the Globar plant of the Carborundum Co.

Dilip K. Das – now project manager at National Research Corp., Cambridge, Mass.

Theodore T. Magel – from assistant to the vice-president and technical director to director of quality control, Allegheny Ludlum Steel Corp., Pittsburgh.

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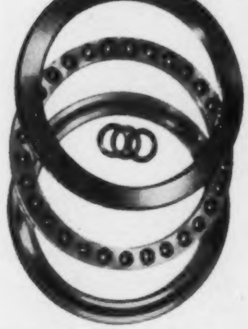

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Write for Ajax Bulletin 700 for details.

AJAX ELECTRIC COMPANY
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Circle 1833 on Page 48-B

Personals . . .

Charles W. Schuck – formerly in charge of production and research at the Braeburn, Pa., plant of Braeburn Alloy Steel Corp., a subsidiary of Continental Copper and Steel Industries, Inc., now executive vice-president. He was also named chief operating officer for the Braeburn Alloy Steel division.

John S. Smart, Jr., general sales manager, American Smelting and Refining Co. – elected president for 1961 of the Metallurgical Society of A.I.M.E.

William Jones – retired as manager of magnetic steel products for Armco Steel Corp., Middletown, Ohio, after 42 years of service with the company.

A. Allan Bates, vice-president for research and development, Portland Cement Assoc., Skokie, Ill. – received the 1960 Kennedy Award of the American Concrete Institute.

Watt W. Webb – from coordinator of the fundamental research group to assistant director of research, Union Carbide Metals Co., a division of Union Carbide Corp., Niagara Falls, N.Y.

Edmund Horner – now research chemist, MacDermid Inc., Waterbury, Conn.

Cyril Stanley Smith – left the University of Chicago, where he had been professor of metallurgy since 1946 and first director of the Institute of Metals, to accept an appointment as institute professor at Massachusetts Institute of Technology.

Alfred H. Petersen – transferred from Lockheed Aircraft Corp.'s California Div. to the Missiles and Space Div. at Sunnyvale, Calif., as manager of production engineering.

John E. Niesse – from supervisor, development engineering, high-temperature materials project in the research and development division of Carborundum Co., Niagara Falls, N.Y., to manager of the division's process development department.

Ernest R. Howard – now manager of the newly created thermostat metals applications engineering department at Metals & Controls Inc., Attleboro, Mass.

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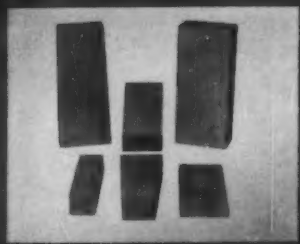

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Circle 1835 on Page 48-B

Metals Engineering Digest

. . . Interpretative Reports of World-Wide Developments

Welding Engineers Meet in California

Report on the Western Welding Technical Conference presented by the Santa Clara Valley Section of the American Welding Society, October 1960, San Jose, Calif. Other papers were discussed last month.

ALUMINUM PRODUCERS ARE COUNTING on future growth in population to spur the increased application of the metal and its alloys. With that growth will come more emphasis on welded structures. Already there are growing applications for welded aluminum products in residential construction, air conditioning and electrical equipment, and household appliances. In the transportation industry the prospect for aluminum looks brighter than ever before, according to C. B. Robinson (Air Reduction Co.) who spoke on the application of welded aluminum alloys. Parts on trucks, trailers, military vehicles and automobiles are being made of the light metal to decrease weight and thus increase pay loads.

Because of their excellent low-temperature properties, certain aluminum alloys, especially those in the 5000 series, are being used in cryogenic applications. Figure 1 shows hemispherical head assemblies of aluminum being welded automatically. The heads are used on trailers which carry liquid oxygen.

Welding Aluminum

Because it eliminates the need for fluxes, the inert-gas method has become one of the most prominent techniques for welding aluminum. Paul Dickerson (Aluminum Co. of America), in describing some of its aspects, stated that the method has permitted many aluminum alloys to be joined by welding, including a wider range of heat treatable alloys that cannot be joined by gas or atomic-hydrogen welding. In inert-gas welding, the operator can see what he is doing without flux obscuring the joint. It is also faster than other techniques and results

Fig. 1 – Special Jigs and Fixtures Aid in Welding This Head Assembly for an All-Aluminum Lox Trailer

Welding . . .

in a smaller heat-affected zone and higher strength in that area.

Resistance welding of aluminum is also feasible as are flash welding, pressure welding and ultrasonic welding. In fact, practically every basic welding process known can be used for joining aluminum.

The non-heat-treatable aluminum alloys are strengthened only by work hardening. After being cold worked, they soften quickly at welding temperature. As a result, the heat-affected zone is weaker than the base metal. For this reason, designs employing the non-heat-treatable alloys must be based on the annealed properties of the metal unless a method can be developed to work harden the heat-affected zone.

Heat Treatable Alloys

Heat treatable aluminum alloys require a longer time at welding temperature (in some instances several hours) before softening occurs in the heat-affected zone. With the exception of 2219 alloy, those in the 2000 and 7000 series are not usually welded because copper and zinc precipitates form at the grain boundaries in the heat-affected zones making them anodic to the rest of the material and susceptible to corrosion. This effect can be corrected, however, by heat treating after welding. Precipitation can also cause cracking during welding.

The more rapidly the heat treatable alloys are welded, the stronger the heat-affected zones. In some instances, hold-down fixtures are used to draw out the welding heat as rapidly as possible. If 6061 aluminum alloy is welded as rapidly as 4 to 5 ft. per min., little or no heat-affected zone results.

Welding High-Temperature Alloys

For many years the petroleum, petrochemical, and chemical industries were the primary users of cobalt and nickel-base alloys, but now the aerospace industry is demanding more and more of these materials.

In welding precipitation-hardening alloys such as René 41 which contain aluminum and titanium, cracking is frequently encountered, particularly when heat treating these materials after welding. It occurs because of complex brittle compounds which form at the grain

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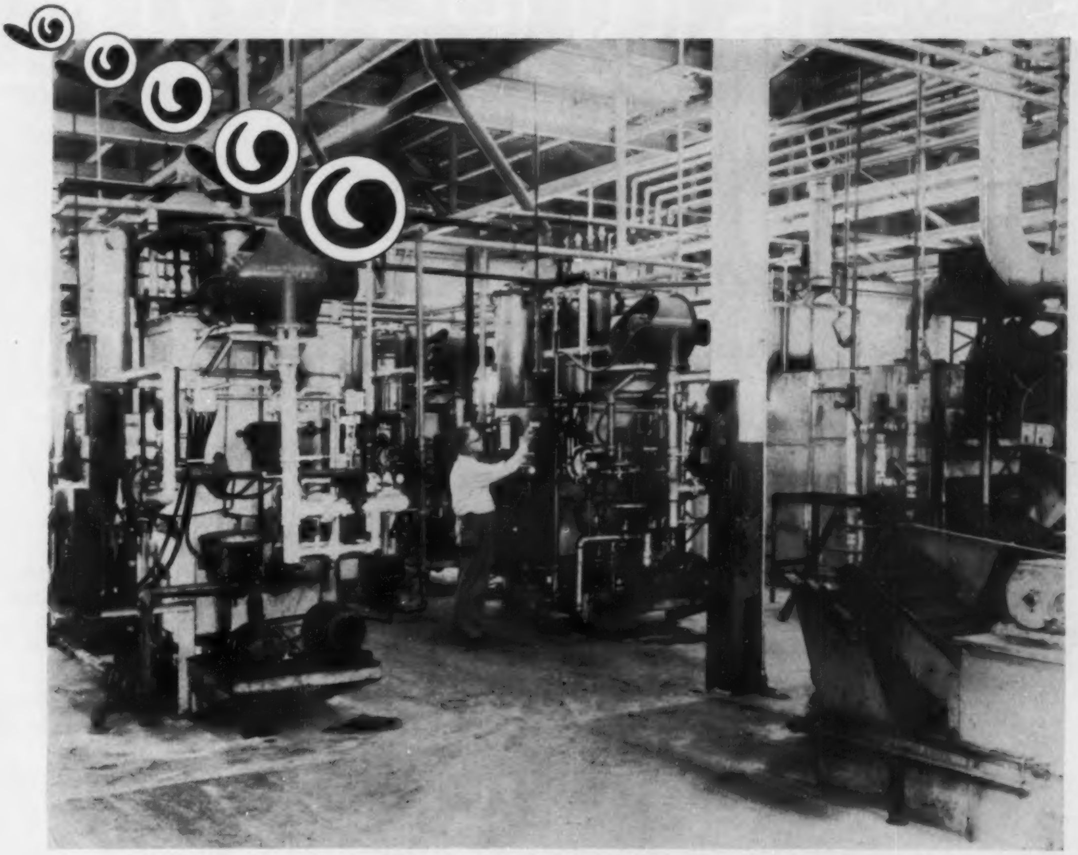

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Circle 1839 on Page 48-B

Welding . . .

boundaries. This point was made by R. D. Culbertson (Haynes Stellite Co.). Cracking can be minimized in these alloys by hot working them using a finishing temperature of 1950 to 1975° F. instead of 2050° F. where maximum structural strength is obtained. At 1950° F. all constituents are not put into solution, and cracking is reduced. The aging treatment gives some improvement in hot ductility of these alloys and also reduces stresses built up in welding.

Hastelloy C, once used primarily for its corrosion resistance but now considered a good high-temperature alloy, has fairly good weldability. For best corrosion resistance, however, the weld must be solution heat treated. The optimum stress-relieving temperatures after welding are 1100 to 1200° F., but in this range Hastelloy C is put into a sensitized condition. Therefore, after welding, if the weld is too large or is not adaptable to solution heat treatment, it is generally stress relieved at a maximum of 1000° F. (preferably below 800° F.) for up to 24 hr.

It was also brought out that Hastelloy C can be stabilized by heat treating at 2050° F. which spheroidizes the carbides. The over-all corrosion resistance is not as good in this condition as it is in the solution heat treated condition, but stabilizing does prevent "knife-line" corrosion in the heat-affected zones.

Hastelloy B is a nickel-base alloy with about 28% molybdenum. Designed for corrosion resistance to reducing acids, it is also suitable for service at 1300° F. Like Hastelloy C, it must not be stress relieved at temperatures above 1000° F. after welding; otherwise it will become seriously sensitized and accelerated corrosion will result in service. Hastelloy B can be stabilized at 1975° F. to prevent "knife-line" corrosion attack in the heat-affected zone.

Hastelloy F contains columbium and tantalum. These elements tie up the carbon and prevent sensitization during welding; therefore "knife-line" corrosion attack is not a problem.

Haynes Alloy No. 25 is a cobalt-base alloy strengthened by solid


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Circle 1840 on Page 48-B

Circle 1841 on Page 48-B

Welding . . .

solution which can be put into service after welding without additional heat treatment. The precipitate (Co_2W) that occurs in this alloy does not provide increased strength but reduces room-temperature ductility after welding. Ductility increases at elevated temperatures where this alloy is used.

Cracking

Nickel and cobalt-base alloys experience cracks similar to hot tearing of castings and generally where liquation of grain-boundary constituents occur in the heat-affected zones. These cracks usually run perpendicular to the direction of welding. Longitudinal cracks are also encountered in the heat-affected zone about ⅛ in. away from the weld. Microcracks occurring in the interstices of the dendrites in the weld are another cause of trouble in welding these alloys. They occur primarily in sections over 1 in. thick.

To overcome cracking tendencies during welding, the alloys should be welded under these conditions:

- Do not use excessive hold-down pressures on the part during welding. This is especially true when joining metals having dissimilar coefficients of expansion.
- Maintain low interpass temperatures with adequate heat control.
- Use copper backup bars and shoes to extract heat from the weld as rapidly as possible.
- Use the stringer-bead welding technique. Weaving builds up stresses across the welds.
- Poor bead contour causes cracking in welds under high restraint.
- Keep all welding surfaces clean. Cracks originating at defects or inclusions can grow during welding.

Certain elements also cause cracks. For instance, silicon in greater amounts than necessary for deoxidizing results in microfissuring. Columbium in greater quantity than needed for stabilizing an alloy can also lead to hot cracking. Boron content should be kept below 0.020%. Aluminum and titanium also add to welding difficulties and should be kept as low as possible.

Vacuum Systems

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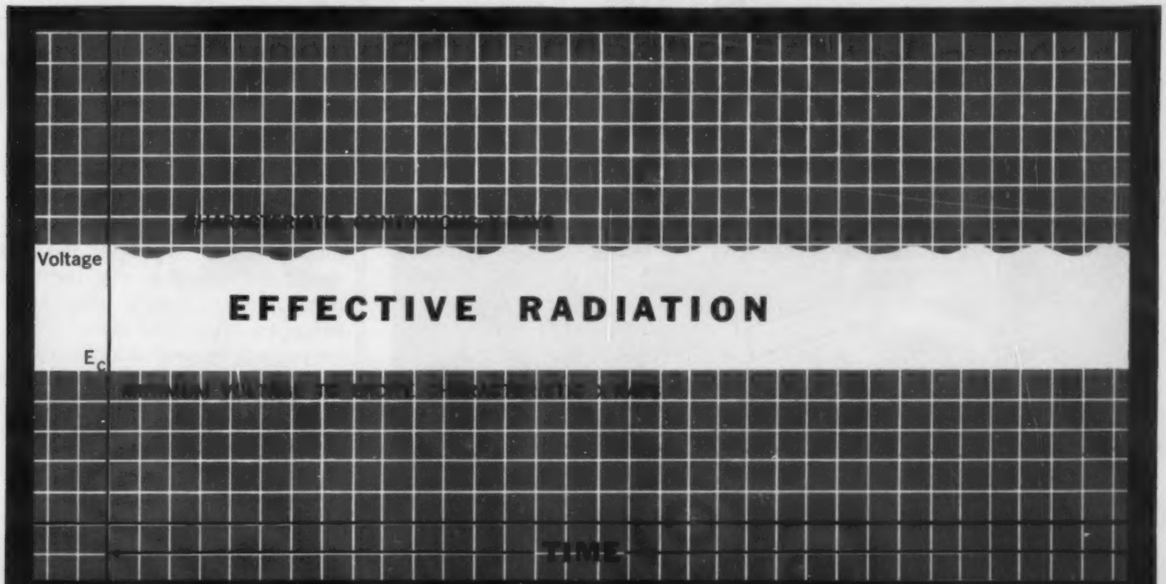

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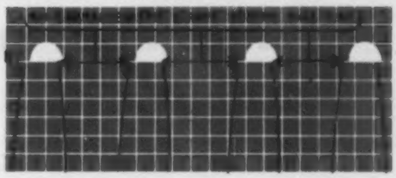

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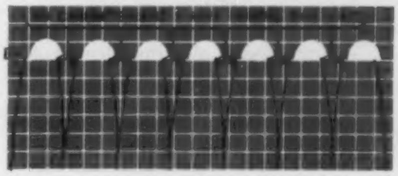

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Circle 1842 on Page 48-B

Welding . . .

eral ease of fabrication and their strength, ductility and low vapor pressure.

In discussing methods for joining materials for vacuum systems, R. H. Rhoades (Sylvania Electric Co.) listed a number of recommended practices. He stated that units should be designed for self-jigging during brazing. If possible, the joint should be located so that the base metal is up to brazing temperature before the filler metal melts. When copper is to be used as a filler metal, tight metal-to-metal fits are recommended. The gap should not exceed 0.020 in. Also, parts should be designed so that radically differ-

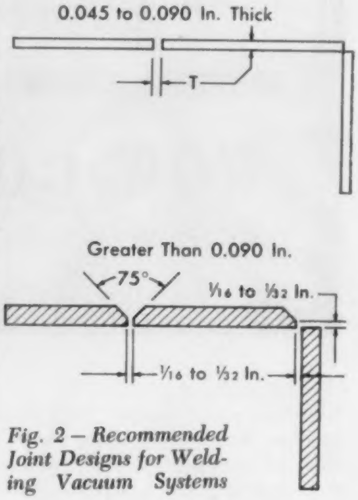

Fig. 2 – Recommended Joint Designs for Welding Vacuum Systems

ent thicknesses are not being brazed. This situation gives uneven heating and, in many instances, unsatisfactory brazing. Brazing in vacuum or dry hydrogen has proved to be advantageous.

For inert-gas or heliarc welding, joint designs should be made as shown in Fig. 2. The usual design, where two edges are bent 90° and welded together, has a disadvantage in that a built-in dirt trap is made and a notch is created at the weld seal. For materials 0.045 to 0.090 in. thick the joint shown in Fig. 2, top, is satisfactory. If the materials are over 0.090 in. in thickness, beveled joints, as illustrated in Fig. 2, bottom, should be used.

In instances where heavy flanges are welded to the part, filler rod

(Continued on p. 150)

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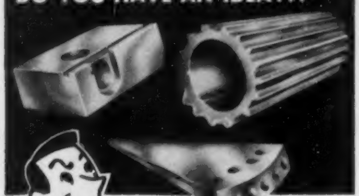

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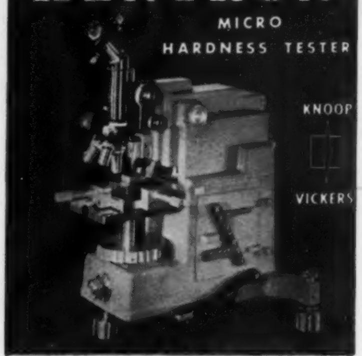

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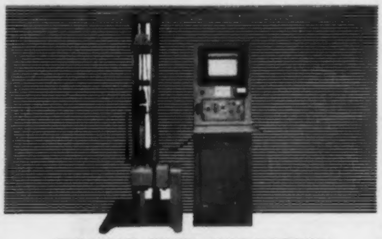

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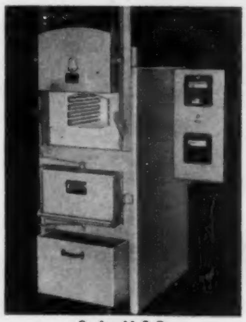
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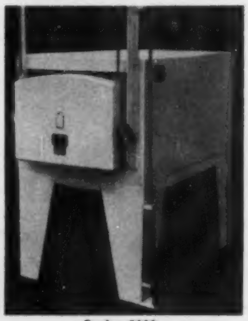
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Circle 58 on Page 48-B

Welding . . .

should be employed. Wherever possible, the reverse side of the part should be protected against oxidation during welding. Cellophane tape formed as a channel to permit the flow of inert gas along the reverse side of the weld provides good protection.

If the root cannot be protected against oxidation, it should be ground or sanded off to remove oxides and excess weld metal.

In welding round seams, such as those on large-diameter tubes, the best welds are made between one o'clock and two o'clock up hill. The filler metal should be melted in the puddle and not in the arc. This gives more control over penetration of the weld bead. Mr. Rhoades recommended that the weld puddle be shaped by angling the torch about 15° during welding to control penetration. The weld should be ended outside the joint in the base metal to prevent crater cracks.

R. C. Bertossa

Corrosion of Stainless Steels

Digest of "General and Intergranular Corrosion of Austenitic Stainless Steels in Acids", by Michael A. Streicher, *Journal* of the Electrochemical Society, Vol. 106, No. 3, March 1959, p. 161-180.

The intensity of intergranular attack on stainless steels exposed to certain acid solutions may range from light etching of grain boundaries to intense penetration which may lead to loss of mechanical strength or even disintegration of the metal. The difference in the rate of corrosion of the grain-boundary zones of the grain faces determines whether corrosion is predominantly intergranular or general. The difference in rates is determined by the structure and composition of the grain boundaries and by the composition of the corroding solution.

In this paper the author presents a detailed study of the mode of intergranular attack in *(a)* boiling 65% nitric acid, *(b)* copper sulfate-sulfuric acid and *(c)* ferric sulfate-sulfuric acid solutions. Solutions *(a)* and *(b)* are now used, and *(c)* has been pro-

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posed as an evaluation test for intergranular corrosion susceptibility. Special attention is given in the paper to the electrochemical action of cations encountered in these solutions either as inhibitors or corrosion products and to metallurgical factors, including chromium carbides, sigma phase and grain size. The steels investigated were Type 304, 316 and 316 L.

Corrosion in Nitric Acid

The corrosion of Type 304 heated for various lengths of time at 1250° F. is shown in Fig. 1. The author shows that intergranular attack occurs in annealed material, but the rate is so slow that it does not lead to dislodgement of grains, hence,

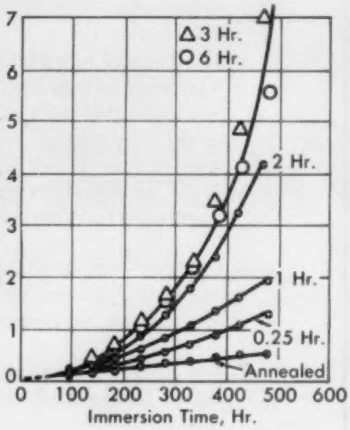

Fig. 1 — Corrosion of Type Boiling 65% Nitric Acid. (For conversion, 1.0 g. per sq.dm in 240 hr. equals 0.0015 in. per month)

the over-all rate of attack is low. In heated samples, which are susceptible to accelerated intergranular attack, high corrosion losses are due to undermining and dislodgement of grains. The type of surface finish affects the corrosion rates which are related to the absolute area of exposure rather than to the effect of potential metal deformation or stress. The apparatus for measuring electrode potentials is described.

The influence of chromium as a corrosion product was investigated by adding trivalent chromium to nitric acid solutions. The addition of 0.005 mole-1. of trivalent chromium markedly increases the corrosion rate of annealed Type 304 as a result of accelerated intergranular attack with grain dislodgement. Trivalent chromium oxidizes to hexavalent chromium which is responsible for the accelerated attack. Direct additions of hexavalent chromium speed grain-boundary attack, not only in Type 304 but in stabilized Type 347 and ferritic Type 430. Accumulation of corrosion products in grain-boundary grooves intensifies the grooving action.

The influence of heat treatment (as related to chromium carbide and sigma formation) on corrosion losses in nitric acid are described. The limit of carbon solubility in the 1050 to 1300° F. range is placed at 0.007 to 0.009%. Orientation of adjacent grains is shown to be of importance in regard to preferential attack on annealed steel, and also to the location of carbide precipitates which leads to intense grain-boundary attack. Susceptibility to intergranular attack on sensitized steel could not be detected by electrode potential measurements which suggest that dissolution is under anodic control. In other words, the greater rate of intergranular attack is a result of a lower polarizability as compared to the grain boundaries of annealed specimens. Sigma accelerates intergranular attack in nitric acid even when the sigma is not detectable in the microstructure.

The author has developed a 120-hr. ferric sulfate-50% sulfuric acid test for revealing the chromium carbide type of susceptibility to intergranular attack. Stainless steel dissolves at a rapid rate in boiling 50% sulfuric acid, but the attack is inhibited by as little as 0.8 g. of ferric sulfate in 600 ml. of 50% acid. Clues to the mechanism of this inhibition are the absence of hydrogen gas bubbles and the dissolution of excess ferric sulfate during the rapid corrosion of sensitized samples. In the absence of an inhibitor, the corrosion of stainless steels proceeds by dissolution of divalent iron, chromium and nickel, which results in the discharge of hydrogen at cathodic areas. In the presence of ferric ions, the hydrogen reaction is replaced by a reduction of ferric ions which results in consumption of the inhibitor. Experiments showed that the dissolution of 1 g. of stainless

steel is accompanied by the consumption of 9 g. of ferric sulfate which is in good agreement with a calculated value of 9.7 g.

The potential of 18-8 steel in boiling 50% H_2SO_4 is −0.34 v. With ferric ions, the potential changes about 1 v. in the noble direction to +0.70 v. When additions of small amounts of ferrous ions are made to the ferric sulfate-sulfuric acid solution, the potential of stainless steel becomes equal to that of the platinum electrode. Thus, the anodic areas are polarized to the potential of the cathodic areas on which the reduction of ferric ions takes place. The potential is the same for annealed and sensitized steel, and is independent of acid concentration. In contrast to the behavior in nitric acid, corrosion products do not affect corrosion in ferric sulfate-sulfuric acid solutions.

Ferric ions greatly retard general corrosion, but intergranular attack cannot be suppressed. This is due to lower polarizability of the metal in grain-boundary zones containing chromium carbides. As the concentration of sulfuric acid is increased from 30 to 60%, there is a large increase in intergranular corrosion of steel containing chromium carbides. General corrosion also increases as the acid concentration increases. At a given length of time, the ratio of intergranular attack to general attack is a measure of the sensitivity of a solution to detect susceptibility to intergranular attack. In this regard, the ferric sulfate-sulfuric acid solution produces grain dislodgement at a rate about twice that of nitric acid. This means that a 120-hr. test is equivalent to the standard 240-hr. nitric acid test. The test can be further accelerated by using ferric nitrate, and it may be possible to develop a 24-hr. ferric nitrate-sulfuric acid test.

The copper sulfate-sulfuric acid test is used to detect susceptibility to intergranular attack due to the presence of chromium carbides. With this solution, general attack is very low, and the nature of the grain-boundary attack is such that dislodgement of grains does not occur. As a result, the change in weight, even with sensitized steel, is very small, and it is necessary to evaluate the test by measuring the change in a physical property (such as electrical resistance) produced by the

Corrosion . . .

corrosive attack. The author confirmed previous work by Rocha that attack can be greatly accelerated by the immersion of metallic copper. The greatest effect was observed with copper in contact with the steel. The type of intergranular attack was not changed by the immersed copper. Electrode potential measurements were employed to determine the mechanism of dissolution as well as to provide an interpretation of the action of metallic copper. The results showed that metallic copper changes the potential of the stainless steel in the anodic direction, and that corrosion in copper sulfate-sulfuric acid solutions is controlled by the polarizability of anodic areas. Data on the influence of heating time at 1250° F. and on the effect of dissolved ferrous ions are also presented. Ferrous ions do not affect the weight loss but may reduce the depth of penetration. The presence of ferrous ions suppresses the shift in potential in the anodic direction which is caused by the reduction of cupric ions to cuprous ions.

In the concluding section of the paper, the author compares the three solutions in regard to the type of intergranular attack. In nitric acid, a high rate of grain surface corrosion leads to grain-boundary widening and profuse grain dropping, whereas the lower rate of grain-surface corrosion in the other two solutions leads to intense intergranular attack with less grain dislodgement. The separation of these effects is more pronounced in Type 316 than in Type 304.

In addition to the effect of solution on the type of intergranular attack, information is provided on the influence of chromium carbide, sigma phase and grain size. The three previously mentioned solutions as well as a nitric-hydrofluoric acid and an oxalic acid etch may be used to show susceptibility to intergranular attack due to chromium carbides. Of these five tests, only the nitric acid test will show susceptibility to attack due to the presence of sigma. The effect of grain size depends on the testing solution and the method of measurement (weight loss or resistance change).

A. J. Lena

Tensile Properties of Titanium Alloy

Digest of "Tensile Properties of 6Al-4V Titanium-Alloy Sheet Under Rapid-Heating and Constant-Temperature Conditions", by Howard L. Price, N.A.S.A. Technical Note D-121, National Aeronautics and Space Administration, Washington, D.C.

Under rapid-heating conditions, the strength of 6 Al, 4 V titanium may be much higher than that measured in the usual elevated-temperature test. The strength can be predicted by master curves and temperature rate parameters, as demonstrated by recent work at Langley Research Center.

In the rapid-heating technique described in this paper, heat treated 6 Al, 4 V titanium sheet is stressed by dead-weight loading, then heated electrically at rates ranging from 0.2 to 100° F. per sec. Strain and tem-

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Tensile Properties . . .

perature are measured continuously. The temperatures at which yield and rupture occur are the criteria of performance.

Before plastic deformation occurs in this test, all the specimens at a given stress level follow the same temperature-deformation curve. This curve is the sum of thermal and elastic strains. But as temperature rises, the curves turn away from the thermal-elastic line, with the specimen heated at the lower rates yielding first – in other words, at lower temperatures. There is a linear relationship between the yield, or rupture, temperature and the logarithm of the temperature rate.

The results of these rapid-heating tests are compared with data obtained in conventional tensile tests at elevated temperatures. Below 800° F., the conventional yield strength is higher than that obtained in rapid-heating tests. But above 800° F., and at the rapid heating rate of 100° F. per sec., the yield strength is appreciably greater than the conventional yield strength. At 1200° F. it is nearly three times as great. At all rapid-heating rates, the rupture strength is well above the tensile ultimate strength.

This paper presents the result of the rapid heating tests as a master curve, shown in Fig. 1.

This figure shows strength as a function of yield or rupture temperature (T) and temperature rate ($\dot{T}$). The two temperature factors are combined in the parameter:

$$\frac{T-300}{7.5 + \log_{10} \dot{T}}$$

By using the master curve, yield or

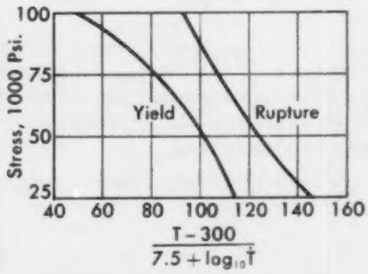
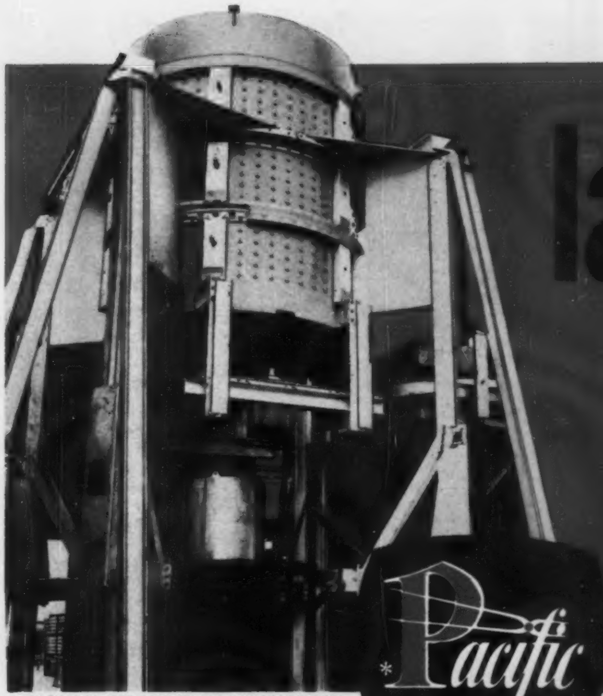


Fig. 1 – Master Yield and Rupture-Stress Curves for 6 Al, 4 V Titanium Alloy Sheet. T is in ° F. and $\dot{T}$ is in ° F. per sec.



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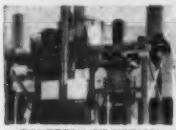

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Tensile Properties . . .

rupture temperature can be predicted for conditions other than those actually tested.

A phenomenological relation between stress, yield temperature, and temperature rate is also discussed. The equation uses constants determined from tensile creep data. There is good agreement between the equation and experimental data at high temperatures but not at low temperatures.

The work reported in this paper shows that under rapid-heating conditions strengths can differ appreciably from those found in a standard tensile test, but the strength levels can be predicted by a master curve and a temperature rate parameter.

B. L. Shakely

Phase Transformations

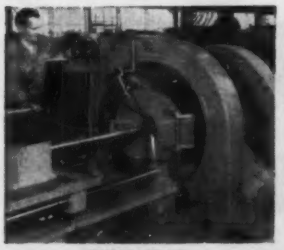
Digest of "Effect of Applied Tensile Stress on Phase Transformations in Steel", by L. F. Porter and P. C. Rosenthal, *Acta Metallurgica*, Vol. 7, July 1959, p. 504-514.

The paper describes the work carried out to obtain a unified picture of the effect of applied tensile stress on the bainite, pearlite and martensite transformations in a eutectoid carbon steel.

An apparatus was developed which could record a specimen's change of electrical resistivity and its cooling rate at the same time. Resistivity measurements, corrected for any plastic deformation during the test, were converted to approximate per cent transformations.

Test results could be divided into three groups: results obtained on isothermal tests in the bainite region, less complete results obtained isothermally and by continuous cooling in the pearlite range, and results obtained from the martensite transformation on quenching.

In the bainite region, transformation characteristics were determined for a series of increasing applied uniaxial tensile stresses at isothermal temperatures of 260° C. (500° F.), 316° C. (600° F.), and 371° C. (700° F.) Above a certain threshold stress, an applied tensile stress markedly speeds the transformation. It appears that the degree of acceleration, as measured by the decrease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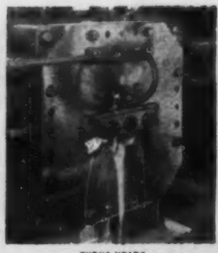
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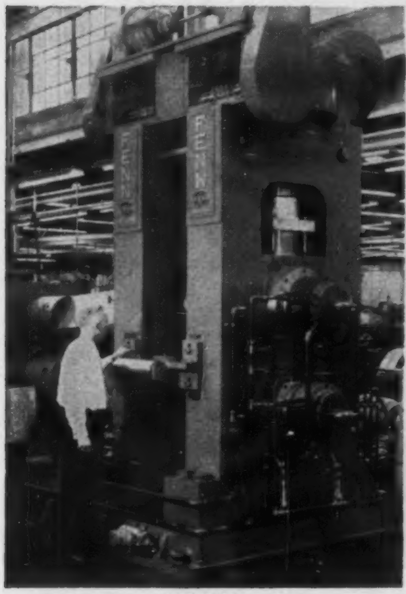

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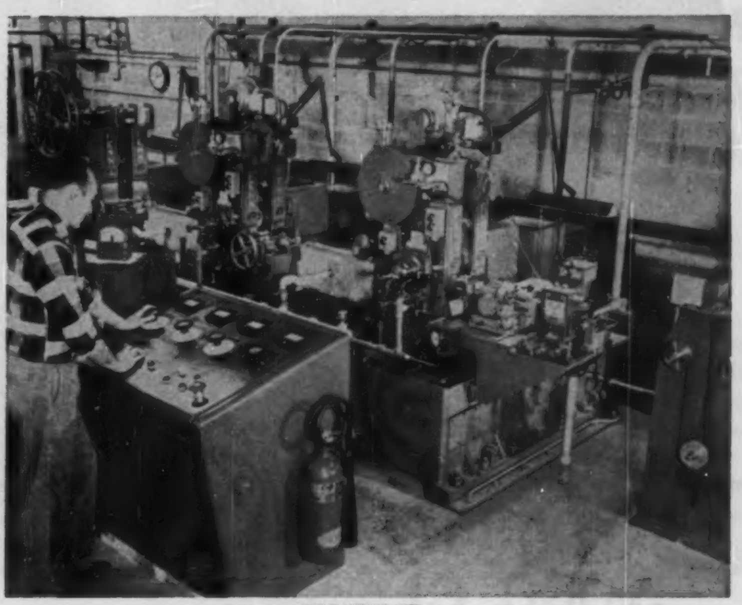
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in time to achieve a given amount of transformation, is a linear function of the applied stress, especially at the lower stress levels. Figure 1 shows the manner in which the applied stress decreases the transformation time. The threshold stresses are 8000 psi. at 260° C. (500° F.), 7000 psi. at 316° C. (600° F.), and 6000 psi. at 371° C. (700° F.). The applied tensile stress has a greater effect on the early stages of transformation than on the later stages, and it was found that, shortly before evidence of transformation was indicated by a change in electrical resistance, the specimen began to extend plastically at a rapid rate.

The rapid change in transformation kinetics with temperature on the pearlite range made it difficult to carry out an adequate number of

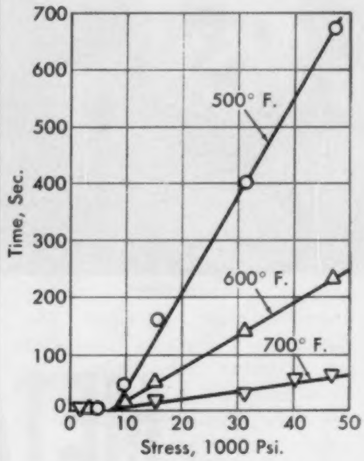

Fig. 1 – Effect of Applied Stress on the Isothermal Transformation of Bainite

tests in this range. The results obtained, however, did indicate that transformation was accelerated by stresses below 4000 psi. Again, rapid extension was observed to occur slightly before the resistance measurements indicated that transformation was in progress. As with the bainite data, it was possible to determine a threshold stress for accelerated transformation. This stress was 2000 psi. compared with the 8000 psi. for the bainite transformation at 260° C. (500° F.).

In the martensite transformation, it was again noted that rapid exten-

Phase Transformations . . .

sion occurred during transformation. Figure 2 shows that the M_s temperature is not affected until stresses over 28,500 psi. are applied.

In general, the results are quite different from those obtained previously for bainite and pearlite. It was found that the threshold stress for increased extension is very low, about 1000 psi., while no effect on the M_s temperature was observed

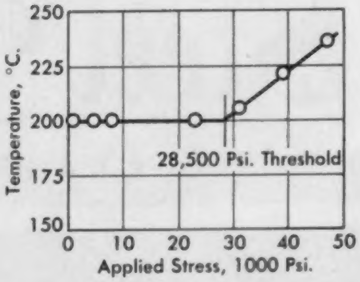

Fig. 2 — Effect of Stress on the M_s Temperature

until a stress of about 28,500 psi. was reached. With applied stresses over the threshold, the stress-induced transformation occurring above 200° C. (400° F.) — the normal M_s temperature — progresses at a much slower rate with decreasing temperature than does the normal transformation occurring below 200° C. In simple terms, the stress-induced transformation occurs and progresses slowly above 200° C. But, when the normal M_s temperature is reached, normal transformation begins and progresses just as if no stress was present.

The explanation for the above phenomenon can be based on the dislocation theory. The authors propose that, on transformation to pearlite and bainite, the threshold stress is the effective stress required to dislodge dislocations from their sources. These dislocations then move to the grain boundaries or other barriers where they form piled-up arrays. It is then possible for the stress concentration, built up at the leading dislocation of the pile ups, to be responsible for the increased rates of transformation.

The low threshold stress for plastic extension observed on transformation to martensite may be explained by the hypothesis that the kinetic energy released (when a plate of martensite forms) is capable of dislodging dislocations from their sources and forces pile ups against the grain boundaries. Thus, only a small additional applied stress is necessary to activate slip in adjacent grains and produce gross plastic deformation. The high threshold stress needed to raise the M_s temperature is difficult to explain on the basis of our present knowledge of the mechanism of martensite transformation. W. A. MORGAN

A New Alloy Production Process

Digest of "New Process for Production of Alloys", by G. I. Pogodin-Alekseev and V. V. Zaboleev-Zotov, *Liteinoe Proizvodstvo*, No. 7, July 1958, p. 25-26.

ESSENTIALLY, ALL INDUSTRIAL ALLOYS are produced from castings in which the alloy components have been completely liquified, or from powder process techniques which

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New Alloy Process . . .

give special structure, phase composition and properties. A new process giving a suspended dispersion may have advantages over the more conventional processes. In this process, the alloy base is melted in a crucible and subjected to ultrasonic vibrations, while the principal component is added as a solid in powder form or as a rod of the desired metal joined to the emitter.

This process has been successfully applied to an alloy of tungsten carbide in lead. Lead was melted and superheated to 400° C. (750° F.) and subjected to ultrasonic vibration with a frequency of about 21,500 cycles per sec. Tungsten carbide powder (micron-sized grains) was slowly poured into the melt. After 10 min., heating was stopped and the alloy was cooled in air. When the solidification temperature was reached, vibration was discontinued, and the alloy fully cooled.

Microscopic examination showed that the tungsten carbide particles were uniformly distributed in the lead matrix. If too small a generator is used, some powder will settle to the bottom of the crucible. The remaining powder, however, is uniformly distributed in the matrix.

This process, like powder processes, makes it possible to produce alloys from components which are not mutually soluble as liquids. Also, the phase distribution can be predetermined; this is impossible by casting techniques. When compared to conventional powder processes, this method requires much less powder, and eliminates pressing and sintering. Uniform density can be achieved with greater bond strength among the alloy components than with powder products.

C. O. SMITH

Electronic Nitriding

Digest of "Glow Discharge Nitriding of Steel", by H. Knüppel, K. Brotzmann and F. Eberhard, *Iron and Steel*, October 1959, p. 463 to 468.

NITRIDING, AS A METHOD for hardening steel surfaces, was first introduced about 35 years ago. Its primary advantages (over the other methods of surface hardening) were

Electronic Nitriding . . .

the high hardnesses achieved and the lack of distortion when hardening fully machined surfaces. The method also had two disadvantages: the treatment took a long time and the nitrided layer was brittle. Numerous methods of nitriding were investigated in an effort to eliminate these disadvantages.

One method which showed considerable promise was called glow nitriding. This process uses ionized gases and works as follows: The piece to be nitrided is placed in one end of a tube where it serves as a cathode, the anode being at the other end. Next, the tube is evacuated, and filled with nitrogen gas at a pressure of 5 mm. of mercury. A direct-current voltage, ranging from 100 to 1000 v., is then applied for a predetermined period of time; this nitrides the object.

At present, the size of the piece to be treated is limited by the size of the tube and the available power. To date, therefore, the process has been used for small parts only.

When using this process, precautions must be taken to prevent the glow discharge from changing into an electric arc; such an occurrence could damage the piece being treated, the tube itself and the current supply system. This "changeover" phenomenon has been thoroughly investigated and the causative factors have been found. In the current range of 0 to 1 amp. no changeover can take place, so this is called the "absolute stable range". With currents greater than 1 amp., changeover may take place. This is called the "relative stable range".

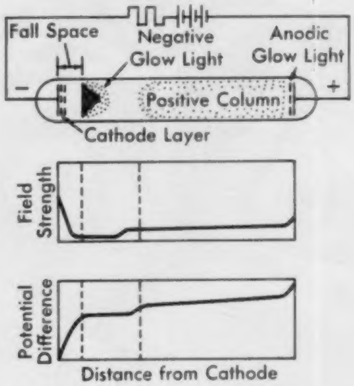
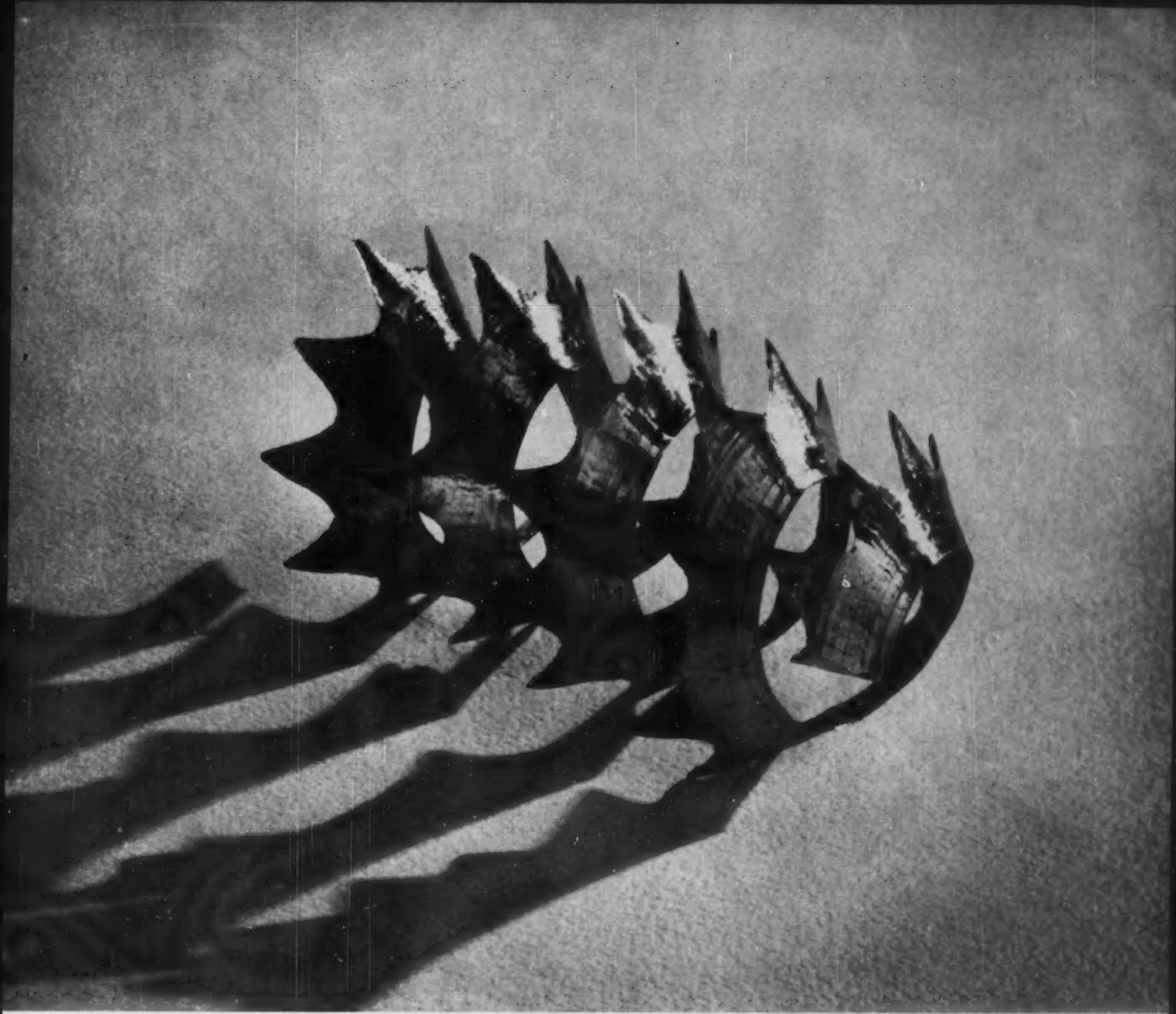


Fig. 1 — Variation of Field Strength and Potential With Distance From Cathode in a Glow Discharge

The current limitation of the absolute stable range limits the maximum usable power to 1 kw. which is insufficient for the technical application of the glow-discharge method. Thus, it is evident that the process *must* operate in the relative stable range. Since changeovers will occur in this range, some method must be devised to extinguish the arc (before it does any damage) and to reignite the glow discharge. Fortunately, there are several control methods available; some protect the workpiece while others protect the current supply system.

A number of the physical factors involved were investigated in an effort to improve the process and to obtain additional knowledge. These factors included, among others, the effect of temperature on hardness and depth of penetration, the effect of gas composition and pressure, and the effect of current density and type



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Electronic Nitriding . . .

of current. The results revealed that temperature differences had no effect on hardness, and the depth of penetration was dependent only on the treatment time. Furthermore, the type and density of the current had little effect on these factors. In addition, although ammonia was the only gas which could be used for gas nitriding, the glow method could use any nitrogen-hydrogen mixture with a ratio between the limits of 9 to 1 and 1 to 9. The working pressure for the discharge method was found to be between 1 and 10 in. of mercury.

BERNARD TROCK

Better Bearing Alloys

Digest of "A Study of the Metallurgical Properties That Are Necessary for Satisfactory Bearing Performance and the Development of Improved Bearing Alloys for Service up to 1000° F.", by T. V. Philip, A. E. Nehrenberg and G. Steven, WADC Technical Report 57-343, Part II.

THE SUGGESTED MINIMUM HARDNESS required at the operating temperature of a high-temperature rolling contact bearing is Rockwell C-56 to 58. The work reported describes the formulation and evaluation of experimental bearing steels suitable for service up to 1000° F. The analysis of results has clarified the effects of alloying elements on secondary hardness and hot hardness.

Results verified the initial assumption that maximum secondary hardness can be achieved by balancing each carbide forming element with sufficient carbon to form that carbide which produces secondary hardening, namely W_2C, Mo_2C, VC (or V_4C_3), and CbC (or Cb_4C_3). Carbon allocation for chromium was based on $Cr_{23}C_6$ and on Cr_7C_3 in the experiments. Compositions ranging from 0.45 to 1.02% C with chromium constant at about 4.5% were alloyed with from 0.5 to 5% V, from 3 to 9% W and from 3 to 9% Mo. All carbide formers were balanced with carbon except chromium. The steel which was most temper resistant in this first group was used as a base composition for the second group. In this the effect of chro-

Circle 1889 on Page 48-B

mium to carbon balance, chromium to carbon level, and cobalt additions of 5 and 10% were examined as well as substitutions of tungsten for molybdenum and molybdenum for tungsten. The two best compositions of the second group were used as the base analyses for the final group of steels in which atomic ratios 1:1, 1:2, and 2:3 of tungsten to molybdenum were examined as well as substitutions of columbium for vanadium and additions of up to 1.5% Si.

All of the experimental analyses were screened by an austenitizing and tempering survey. Each optimum austenitizing temperature was the highest giving maximum secondary hardening after a 2-hr. temper at 1050° F. without undue grain growth or grain boundary melting. Using the optimum austenitizing treatment, a master tempering curve was determined for each steel by cumulative tempering up to 32 hr. at 950, 1000, 1050, 1100 and 1200° F. Rockwell hardness was plotted against the parameter: $T (20 + \log t) \times 10^{-3}$, where T is absolute temperature (°R.) and t is tempering time in hours. The steels having best room-temperature hardness after tempering to parameter value 33.6 (corresponding to 1000 hr. at 1000° F.) were evaluated further using these tests:

Hot Hardness – Rockwell C hardness was measured at 600, 800 and 1000° F. after optimum hardening and 2 + 2 hr. at 1050° F., after 1000 hr. at 600 and 800° F., and after 500 hr. at 1000° F.

Dimensional Stability – Precision length measurements were made after exposure to time-temperature combinations similar to those preceding hot hardness tests.

Compression – Yield strengths at 0.1 and 0.2% compressive plastic strain were measured at room temperature, 600, 800 and 1000° F. for samples hardened and tempered 2 + 2 hr. at 1050° F. (Rockwell C-68 to 69).

Oxidation Resistance – After specimens were exposed in air at 1000° F. for 1000 hr., scale was removed in hot KOH, weight loss determined, and penetration calculated.

Corrosion Resistance – Finish-ground samples were sealed in pyrex capsules under partial pressure of purified nitrogen, exposed 400 hr. at 400° F. in MIL-7808-C oil and at 600° F. in Octa Decyl Tri Decyl Silane, weight change noted, and examined visually for corrosion.

Metallographic Examination – Samples in the hardened and double tempered condition were examined for carbide distribution on transverse sections. A sample of the final analysis chosen was examined by X-ray diffraction for retained austenite after recommended heat treatment. None was found.

The conclusions of this comprehensive study were:

1. To achieve and maintain desired hot hardness of Rockwell C-56 to 58 at 1000° F., the minimum carbon content is 1.0 to 1.1%.
2. Chromium between 2.5 and 4.5% is essential to develop and maintain high secondary hardness. Carbon allocation for chromium should be based on $M_{23}C_6$.
3. Temper resistance at high hardness levels is improved by 5% Co.
4. Increased tungsten and molybdenum balanced to form M_2C raises the secondary hardness peak to the highest hardness and tempering parameter. Tungsten and molybdenum in an atomic ratio of 1:1 produces better resistance to tempering at high parameters than other ratios or either element alone.
5. Vanadium increases the temper resistance; the optimum level is 2%.
6. Columbium failed to raise secondary hardness and decreased temper resistance when 1.0 to 2.8% were added. (Cont'd. on p. 172)

Circle 1891 on Page 48-B

Bearing Alloys . . .

7. Silicon decreased secondary hardness in the steel tested.

8. Hot hardness at 600, 800 and 1000° F. was lower than room-temperature hardness by 4.1, 6.6, and 9.6 points Rockwell C, respectively, for the steels studied having recovered hardnesses between Rockwell C-65 and 69 at room temperature.

9. Retained austenite prevented dimensional stability for prolonged high-temperature exposure. Cobalt improved dimensional stability.

10. Oxidation metal loss after 1000 hr. at 1000° F. in still air was 3.5 to 23.7 mg. per sq. in. for steels with 4.7 to 2.35% Cr. Silicon improved oxidation resistance.

11. At 400° F. all experimental steels showed better resistance to corrosion by MIL-7808-C oil than S.A.E. 52100. At 600° F. in Octa Decyl Tri Decyl Silane, the experimental steels showed corrosion resistance similar to M-2 steel.

12. The following experimental bearing steel, WB-49, showed the most favorable combination of properties for use up to 1000° F.: 1.09% C, 4.2 Cr, 1.9 V, 6.7 W, 3.7 Mo and 5.2 Co. Recommended heat treatment: Austenitize at 2225° F. and double temper 2 + 2 hr. at 1050° F. Spheroidize anneal: 2 hr. at 1600° F., furnace cool to 1450° F., cool 1450 to 1200° F. at 25° F. per hr., air cool to room temperature to obtain Rockwell C-23.

When austenized at 2275° F. for 10 min. and then tempered, WB-49 had Rockwell C hardness values at room temperature (for 2 hr. and 32 hr.) as follows:

Tempering Temperature	2 Hr.	32 Hr.
950° F.	66	68
1000	67	68
1100	67	65
1200	65	52

When austenitized at 2250° F. for 10 min. and tempered 2 + 2 hr. at 1050° F., WB-49 had Rockwell C hot hardness values as shown in Table I.

The eight most promising experimental steels showed variations in compressive strength for 0.2% offset from 374,000 to 555,000 psi. at room temperature, and from 301,000 to 352,000 psi. at 1000° F. despite the fact that the room temperature

Table I – Rockwell C Hot Hardness Values for WB-49

	Temperature			
	600° F.	800° F.	1000° F.	Room
After 1000 hr. at 600° F.	C-65	C-62	C-59	C-69
After 1000 hr. at 800° F.	65	62	59	69
After 500 hr. at 1000° F.	62	60	57	66

hardness of all were Rockwell C-68 to 69.

Balls ½ in. diameter will be made from a vacuum induction melted 600-lb. melt of analysis WB-49 for fatigue tests. Future work will be devoted to development of a bearing steel with oxidation and corrosion resistance as well as secondary hardness for use up to 1000° F.

W. E. Littman

Radiation Damage

Digest of "Radiation Damage in Ferrous Metals", by D. E. Thomas, *Journal of Metals*, Vol. 11, August 1959, p. 523-527, and "Radiation Damage in Ferrous Materials", by R. E. Smallman, *Iron & Steel*, Vol. 32, No. 5, May 7, 1959, p. 175-180.

There may have been a time when engine designers had to base their design calculations on room temperature properties of the materials, while being well aware that the materials would be used at elevated temperatures. These designers may have been unable to obtain reliable mechanical properties at operating temperatures, and thus had to extrapolate to operating temperatures all such properties as yield stress, hardness, ductility, thermal conductivity and thermal expansivity. Needless to say, this must have been a very unsatisfactory state of affairs.

Some practical-minded materials test engineer – with high temperature testing equipment unavailable to him – may have thought of prepost testing; that is, he may have heated the metal to the operating temperature, and upon cooling to room temperature found that the mechanical properties had grossly changed from the ones he observed before. These changes may have been interpreted as representing the changed behavior "at temperature". From what we know today about transformation, annealing, diffusion and microstructural kinetics, such interpretation would not only be wrong quantitatively but also qualitatively, leading to the belief that under certain conditions the material may have become stronger while in fact "at temperature" it would have been weaker.

The lesson that we can learn from this fictitious analogy between radiation effects and temperature effects


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Radiation Damage . . .

is that we need to do more "in-pile" testing of *all* required properties, just as we are now testing for strength, ductility, expansivity, and the like at temperature. Granted that the equipment and associated instrumentation is expensive and that control of the independent variables in-pile (stress, temperature and neutron flux) is very difficult. It is nevertheless necessary that such experiments must be conducted to establish confidence in the basis of calculations that are now incorporated into nuclear reactor design. It would not be surprising to find that new and unique properties are associated with the new environment, just as temperature revealed the creep problem and as stress-reversals revealed the fatigue problem. In fact, a unique and quite bothersome new property is the radiation-induced volumetric change and in-pile "growth" of metals.

The two papers under review restrict themselves to ferrous metals only. They are intended to summarize what results have been available to the authors and what reasonable interpretations one may marshal in the analysis of the available test data which are nearly all of the pre-post type.

It is agreed that the root of all radiation damage must be found in an atomistic model, since it is because of the action of subatomic particles (alpha, neutrons) or waves (beta and gamma rays) that the damage occurs. Thus, all theories utilize lattice damage as the basic concept, and built the mechanistic model with the help of vacancies, interstitials, replacement collision, thermal spikes, and the like. All of these concepts disorganize the regular space lattice. Hence, they build up internal strains, lock dislocations into immobility, and consequently increase the flow stress and hardness of the metal. These increases in strength do not always occur at the expense of ductility. Counteracting this is the heating effect of gamma radiation or of the reactor surroundings which may approach 1000° F. Such temperatures act to anneal the strained metal, and bring it back toward its original condition. Obviously the result shown by a test piece will be some balance between

Radiation Damage . . .

the hardening mechanisms and annealing effects. This balance will depend on the neutron flux (not only the integrated or total flux but the spectrum from fast to slow neutrons), exposure temperature, cooling rate, and exposure time. (See "Critical Points", *Metal Progress*, December 1959, p. 65). The interpretation of the reported data is thus always based on some thermal history that must be considered concomitant with the exposure to the neutron flux. It is unfortunate that for many reported data neither the temperature nor the neutron flux could be established with desirable certainty. Consequently, many test results could be interpreted as being either due to a small contribution of lattice defects or due to a large contribution of annealing effects.

Table I – Reactor Data

Component	Fast Flux	Integrated Flux	Temperature
Core	$4.2(10)^{14}$ nv.	$2.6(10)^{23}$ nvt.	540 to 750° F.
Thermal shield	$3.6(10)^{12}$	$2.3(10)^{21}$	550 to 575
Pressure-vessel wall	$3.6(10)^{11}$	$2.0(10)^{20}$	500 to 600

A few selected steels are reported in the two papers. Among these are: A.S.T.M. types A 212 B, A 201, A 302 B, stainless steel Types 301, 347, carbon steels with 0.05% C, 0.07% C. and 0.21% C, a few other special steels and pure iron.

Thomas uses the reactor (PWR type) at Shippingport, Pa., as an example to establish orders of magnitude of temperature and exposure which are applicable in the evaluation of test variables. He is assuming an in-pile life of 20 years (see Table I).

Radiation effects in pure iron single crystals are similar to those in nonferrous metals; that is, the yield stress is increased by about 100%, but the maximum stress is only slightly affected. In polycrystalline iron this effect may be so pronounced that it results in a work-softening material instead of the standard unirradiated work-hardening material.

Carbon steels show an appreciable hardness increase after irradiation (of about 15%); the effect of irradiation is less *(a)* the higher the initial hardness (due either to cold work or carbon content) or *(b)* the higher the irradiation temperature. Irradiation temperature and time appear to have a larger effect on the properties than the same temperature and time during annealing after irradiation previously done at a lower temperature. In other words, annealing during irradiation appears to be more effective in decreasing radiation damage than is post-irradiation annealing under equivalent time and temperature.

Smallman is particularly concerned with the decrease of ductility

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While it is not always wise to formulate hard-and-fast rules, the following may be used as a general yardstick:

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Radiation Damage . . .

due to irradiation, exemplified by a pronounced increase in transition temperatures of pressure vessel steels. He refers to a very "elegant theory of brittleness" by Cottrell which not only applies to radiation damage, but was primarily developed for brittle fracture phenomenon in general and equally well applies to yield point phenomenon. Such varied parameters as yield stress, strain rate, grain size, and to some extent even the specimen history can be introduced in the basic equations.

Some workers at the Atomic Energy Research Establishment at Harwell have combined the basic concept of lattice defects created by irradiation with the concepts of this theory and made a few predictions. They have chosen tensile and impact specimens of En2 steel (0.15% C, 0.12 Si, 0.59 Mn, 0.051 S, 0.026 P, 0.15 Ni, 0.01 Cr, 0.15 Mo, 0.06 Co, 0.02 Al, 0.011 N_2) to verify some of their predictions. It was found that the yield stress is approximately proportional to the cube root of the thermal flux. Another consequence of the equation of this theory is that the ductile-brittle transition grain size should decrease as the cube root of the thermal flux. Both of these predictions are verified by some experimental results.

The major hardening was found to be almost independent of testing temperature and is attributed to a "frictional" force on dislocation movement similar to that in precipitation hardening. This implies that the result of neutron irradiation on this steel is to produce dispersed regions of damage throughout the iron lattice which prevent normal passage of dislocations.

Smallman concludes that the simplest and cheapest way to produce a steel with good mechanical properties after irradiation is to obtain a controlled fine-grain size, but only if irradiation takes place at temperatures below, say, 400° F. If the service temperature is about 840° F. (450° C.), much of the damage will anneal out, and the steel can be chosen as in normal engineering practice for its creep strength, oxidation resistance and other desirable properties. Fine-grained steels would then be avoided as would additions such as boron which produce internal gas reactions ($B^{10} + n^1 = Li^7 + He^4$). In the intermediate temperature range, steel selection is complicated by the complex interactions of radiation damage, microstructure, composition and heat treatment (temperature effect). The choice must be based on experimental data of which admittedly there is little available.

Thomas also surveyed existing theories and other proposals to rationalize irradiation effects by analogies. He concludes that "correspondence between irradiation effects and cold work, increased temperature, and alloying has been suggested, but these [proposals] all fail. The evidence is that irradiation places the material in a state which cannot be duplicated by any other means."

F. Forscher

Tempering Steel

Digest of "The Influence of Tempering Time on Some of the Mechanical and Physical Properties of Steel", by J. L. Aston, *Journal* of the Iron and Steel Institute, August 1959, p. 377-382.

THE AUTHOR HAS DETERMINED the change of properties of alloy steels during tempering, particularly for short periods. Times of the order of a few seconds were investigated. Such short tempering periods are important in relation to the application of induction heating.

Rapid heating of ¼-in. diameter specimens, 6 in. long, was accomplished by passing 50 cycle alternating current of about 1500 to 2000 amp. at about 10 v. through the specimens. The bars were then quenched at the site with two wide jets of water which played on opposite sides of the specimen to keep distortion to a minimum.

Tempering tests were carried out on quenched steels of the analyses shown below:

	A	B	C	D
C	0.38%	0.40%	0.47%	0.46%
Mn	0.53	1.40	0.30	0.87
Ni	3.43	0.15	0.05	0.18
Cr	0.12	0.06	0.05	1.00

No heating time was generally less than 1 sec., and the delay or soaking time 1 to 5 sec. To control the short tempering times, all specimens were quenched from the tempering temperature. Tensile specimens ¾ in. long and 0.18 in. diameter were machined from the tempered bars.

Steel A was tempered for periods of 5 sec. and 1 hr. The relationship between hardness and tempering temperature for the two tempering periods was similar in shape, with the shorter period curve being displaced slightly along the temperature axis.

The ductility of steel A however showed marked differences for the two tempering periods as shown in Fig. 1. The rise in ductility associated with increasing tempering temperature occurs at a lower temperature in the specimens tempered for the shorter period.

Steel B was tested in the same way. The strength-to-ductility relationships for the two tempering times are similar to Steel A, but the

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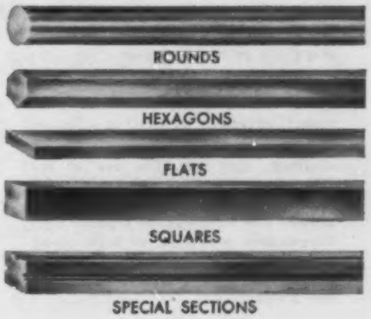

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Circle 1914 on Page 48-B

improvement with a short tempering time is smaller in steel B than in steel A. Results on all of the steels show that a short tempering time is needed to achieve maximum ductility at a definite strength. The alloy steels, however, show more marked effects than the plain carbon steels.

To correlate the electrical resistance heating tests with commercial processes and to obtain sufficient metal for notched bar impact tests, twelve bars of steel D (9 in. by ½ in. diameter) were quenched from 900° C. (1650° F.) into salt at 200° C. (390° F.). Five of these bars were tempered at various temperatures for 1 hr. and quenched into water. The other bars were tempered in an induction furnace for 15 sec. A three-notch Izod test

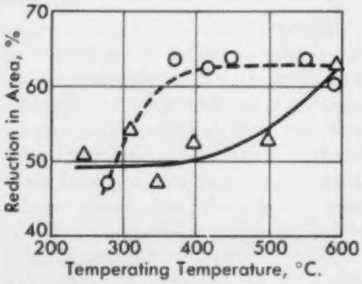

Fig. 1 – Ductility and Tempering Temperature for Steel A. Solid line represents tempering for 1 hr.; dashed line represents tempering for 5 sec.

piece and a 0.375-in. diameter tensile test piece were machined from each of the tempered bars. Mechanical test results are shown in Fig. 2. These results correspond with those obtained on the small test pieces, in that for a given strength a larger reduction in area is obtained in a specimen tempered for a short time than in one tempered to the same hardness in a longer time and at a lower temperature. This effect is most marked on the notched bar results.

The results of the Izod tests suggested that the differences in toughness might be due to temper brittleness so samples of the impact bars were tested microscopically. The samples of steel D had almost the same hardness but a marked differ-

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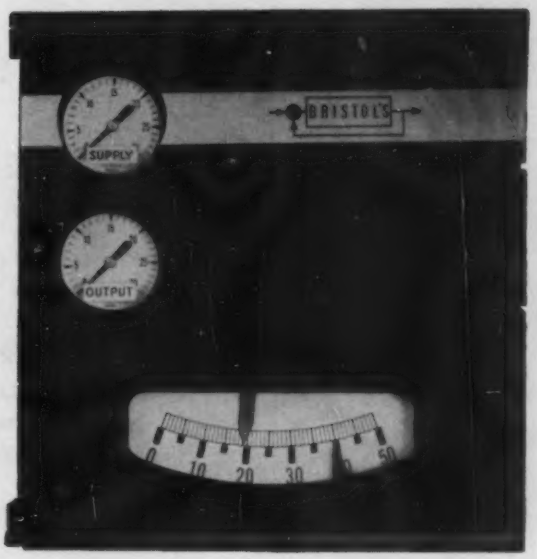

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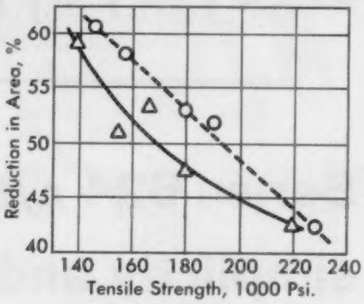
Circle 1916 on Page 48-B

Tempering Steel . . .

ence in Izod value. Microexamination showed a clear difference in the degree of grain-boundary attack. Thus the improvement in ductility in steel D may be due to the avoidance of temper brittleness.

The other steels were also examined in this manner. The steel B (1% Mn) showed a difference between the specimens tempered for a short time and those tempered for a long time, but it was less marked



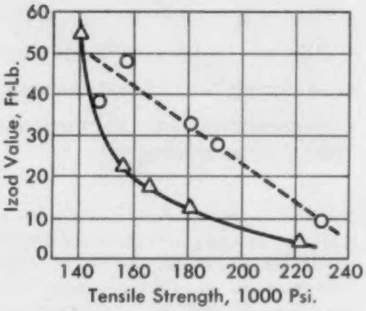


Fig. 2 — Tempering of Steel D. (Top) Strength versus ductility; (bottom) strength versus toughness. Solid line represents tempering for 1 hr.; dashed line represents tempering for 5 sec.

than with steel D. In the other two steels used, no difference in etching characteristics could be recognized with certainty, so it may be that the differences in properties of the 3% Ni steel are due to some other cause. X-ray diffraction experiments on the tempered steels showed that the degree of ferrite-strain in the specimens tempered for different times at the same temperature was similar, so this effect was eliminated.

W. A. MORGAN

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Circle 1919 on Page 48-B

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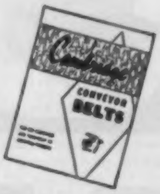

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PORTABLE X-RAY UNITS

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Mark 5F Ultrasonic Flaw Detector

Price for single frequency unit — $1785.00 plus accessories

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- **Clear Presentation** — high brightness cathode ray tube provides easy viewing, even in full daylight.

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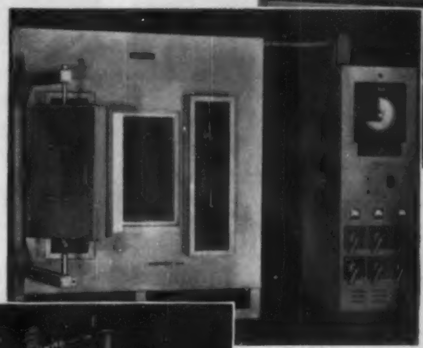
for the CONTROLLED application of heat!

HARROP serves research and manufacturing with standard and special furnaces

Electric — MR Series, Metallic Resistors; radiation or convection heating



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Instrumentation — for any need, both in respect to control and to control forms affecting the time-temperature-atmosphere relations

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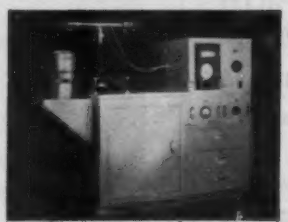

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BEHIND THE BYLINES

The jet engine forgings W. W. Dyrkacz is examining in the photograph below were made from consumable-electrode vacuum-melted A-286. His article on the present and future use of consumable-electrode melting of steels is the first of three this month in our Advances in Vacuum Technology section beginning on p. 65. Manager of quality control at Allegheny Ludlum Steel Corp. in Watervliet, N. Y., he joined the company in 1949 and was associate director of research in charge of high-temperature alloys, valve steels and melting until taking on his present

job in 1956. He received his B.S. degree in metallurgical engineering from Carnegie Institute of Technology.

He's on the roster of several technical groups – including A.S.M. and A.I.M.E. – and has served on various panels of the Materials Advisory Board of the National Academy of Sciences. Much of his time is spent outdoors following various hobbies – fishing, hunting, golfing, gardening and stereo photography.

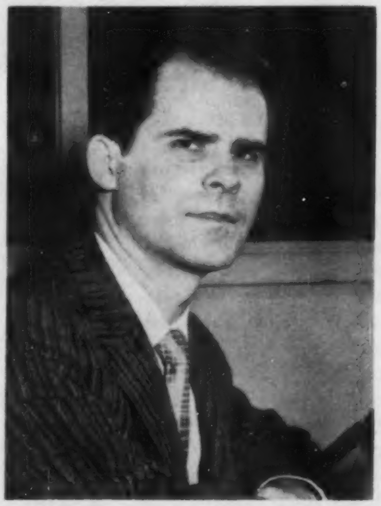
The process of deoxidizing steels by vacuum, which is reported by G. E. Danner and E. Dyble on p. 75 (third in the Advances in Vacuum Technology section), was developed by G. Taylor, superintendent of

the melting department at Erie Forge and Steel Corp., Erie, Pa. Mr. Danner (shown, right, with Mr. Taylor, center, and Mr. Dyble) is director of metallurgy and research at Erie Forge, joining the company in 1951 after 13 years with Alco Products Inc. Mr. Dyble has been metallurgical engineer for the company since 1957 and before that was a manufacturer's representative for a short time and with General Motors' Cleveland Diesel Engine Div. for 15 years.

"AM 355 for Gas Turbine Engines" (p. 79) is based on several years of work by Paul A. Bergman at the Small Aircraft Engine Dept. of the General Electric Co. in West Lynn, Mass. Mr. Bergman (shown examining a corrosion test setup, (right) graduated from Illinois Institute of Technology with a degree in metallurgical engineering and joined G. E. in 1952 where he has specialized in materials developments and process applications engineering of steels and medium-temperature alloys; since 1956 he has worked in the Thomson Engineering Laboratory.

His leisure hours are usually spent in outdoor sports — ranging from skiing and mountaineering to fishing and camping. But if the weather forces him to stay inside, he can always play contract bridge — one of his indoor enthusiasms.

Measuring residual stresses by drilling holes is explained by A. J. Bush (p. 91), an engineer in the materials engineering department of Westinghouse Electric Corp. He received his B.S. degree in mechanical engineering at Carnegie Institute of Technology in 1955 and is now working toward his M.S. degree there. A stress analyst with Lockheed Aricraft after graduation, he then joined Westinghouse where he has worked on developing test equipment for evaluating the performance of materials and on stress analysis problems.



Robert Talmage, one of the pioneers in sintered steel parts production (and author of "Sintered Iron Piston Rings" on p. 89), started work in powder metallurgy with the Moraine Products Div. of General Motors Corp. shortly after graduating from Purdue University in 1935. In 1947 after directing the efforts of several sintered metal plants, he set up an independent consulting practice in the field. Since then he has designed and installed plants for the production of sintered iron, brass and bronze parts (both here and in Europe), served as consultant to a long list of

concerns and developed new methods for applications, such as sinter bonded steel assemblies.

His office is in his home where his wife has always served as his secretary. This effectively combines his main interests – powder metallurgy and home and family. In recent years any spare time has been spent doing work for the Boy Scouts or Church – although he does get in a small amount of skiing.

J. E. Wilson (left), coauthor of "Phase Identification in Nickel-Base Alloys" (p. 94) is manager of continuous process engineering in the industrial heating department of General Electric Co. in Shelbyville, Ind. He joined G. E. ten years ago after graduating from the University of Cincinnati and has worked on new high-temperature turbine blades and contributed to the development of DCM alloy. More recently he was manager of advanced chamber materials engineering in the rocket section at G. E.'s FPD.

J. F. Radavich (right) is assistant professor of physics and engineering science at Purdue University where his interests are centered on high-temperature solid-state metallurgy, with emphasis on phase reactions. He received his Ph. D. from Purdue in 1953, then was granted a one-year post doctoral National Science Foundation Fellowship at Cambridge University.

His family of five children keeps him busy, but he still finds time for golfing and fishing.

Studies of the electron microscope as a tool for examining fractures are underway at the Santa Monica Div. of Douglas Aircraft Co., where Austin Phillips and Guy V. Bennett (who report this new technique,

termed electron microfractography, on p. 97) both work in the metallurgical research section, materials research and process engineering. Mr. Phillips became associated with Douglas Aircraft 19 years ago and is now a research engineer in charge of the electron microscope laboratory. Born in England, he received his university training at U.C.L.A. and U.S.C. Mr. Bennett, who heads metallurgical research, received his B.S. degree in metallurgical engineering in 1950 from the South Dakota School of Mines and Technology and the following year joined Douglas, working seven years on materials and processing development. In 1959 he was assigned his present job.

Investigation of D-31, a new columbium-base alloy, by engineers at Grumman Aircraft Engineering Corp. in Bethpage, L.I., N.Y., resulted in the article on p. 103 by Andrew F. Trabold (left) and Steven Bank. Mr. Trabold, who received a B.S. and M.S. degree in metallurgical engineering from the Polytechnic Institute of Brooklyn, has been with

Grumman since 1956, as group leader of the manufacturing metallurgy group and more recently project coordinator for advanced manufacturing and development for welding and metallurgy. Mr. Bank, a graduate in metallurgical engineering of the Colorado School of Mines, joined Grumman in 1959, working as metallurgist in the manufacturing metallurgy group and now in Mr. Trabold's new group.

"Furnace Brazing of Stainless Steel Assemblies" (p. 108) is based on a paper presented by H. M. (Pete) Webber at a symposium sponsored by the Industrial Heating Equipment Assoc. After graduating from the University of Colorado in 1926 with a B.S. degree in electrical engineering, he joined General Electric Co. where he spent 31 years, mostly in the industrial heating department. Since 1957 he has been manager of the process engineering department for Harper Electric Corp. in Buffalo.

He has seen his son through college and has gotten his daughter off to a similar start, so he now has more time for his major hobby — photography. He also enjoys snatches of swimming, golfing, skiing, skating and music.

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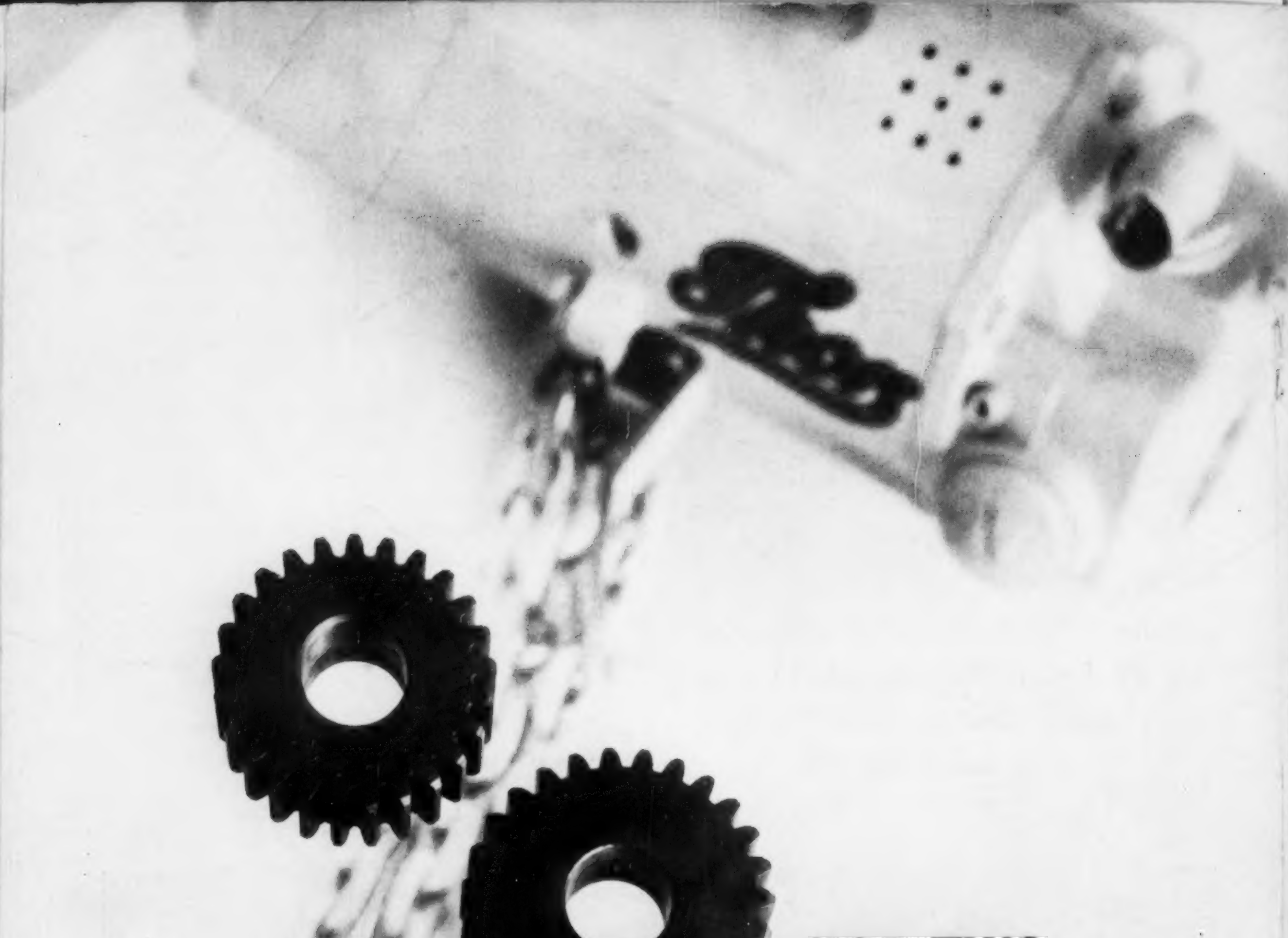

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